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LANSTON'S MONOTYPE MACHINE.

[*Being the report of the Institute, through its Committee on Science and the Arts, on the invention of Tolbert Lanston.*]

[No. 1849.] HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, February 1, 1896.

The Franklin Institute of the State of Pennsylvania, for the Promotion of the Mechanic Arts, acting through its Committee on Science and the Arts, investigating the Lanston monotype machine, reports as follows:

In designing this machine the inventor had the object in view to produce individual types, set in lines of equal length, ready to be formed into columns and locked into chases, for use as a printing surface. Instead of setting previously prepared type, as in the old type-setting machines, he selected a process of casting types in the order of their use, and of setting this type into justified lines, and the lines into a column, to be subsequently separated into pages by hand.

The greatest difficulty encountered in all type-setting machines is the problem of the justification of the lines. This problem has been solved, in this machine, by making the word-space types of a variable thickness, after first determining, by an ingenious plan, the thickness of the word-spaces requisite to make each line of the proper length. This determination must, of course, precede the casting of the line, and this was presumably the initial reason for dividing the process of type-setting into two operations, each of which is performed on a distinct machine.

The first of these machines is in some respects similar to a typewriter, but instead of printing common letters, it is constructed to perforate a ribbon of paper, the locations of the perforations determining, Jacquard-card fashion, the characters which the operator puts into it. For each character two holes are punched through the ribbon, which has previously been provided with two rows of marginal holes that act as racks, by means of which the ribbon is advanced with the necessary regularity.

The key-board is of a rectangular form, the keys being arranged in series of horizontal and vertical lines, and the characters placed on these keys in the following order: The characters are divided into as many groups as there are vertical lines on the key-board; those requiring the least space being placed into the first group, the next larger ones into the second group, and so on. To the first group is assigned a space of five units, to the second one of six units, and so forth. By the depression of each key, two holes are punched into the paper ribbon, in line with the marginal holes forming the rack. These punched holes record the location of the character on the key-board, one hole recording the number of the vertical, and the other that of the horizontal row of keys containing the letter struck. At the same time a mechanism is set into motion by the depression of each key for the object of measuring and indicating the space occupied by the accumulating letters. This mechanism is advanced by the depression of each key, by a number of units corresponding to the number of units of space occupied by the type, and this advance is indicated by an

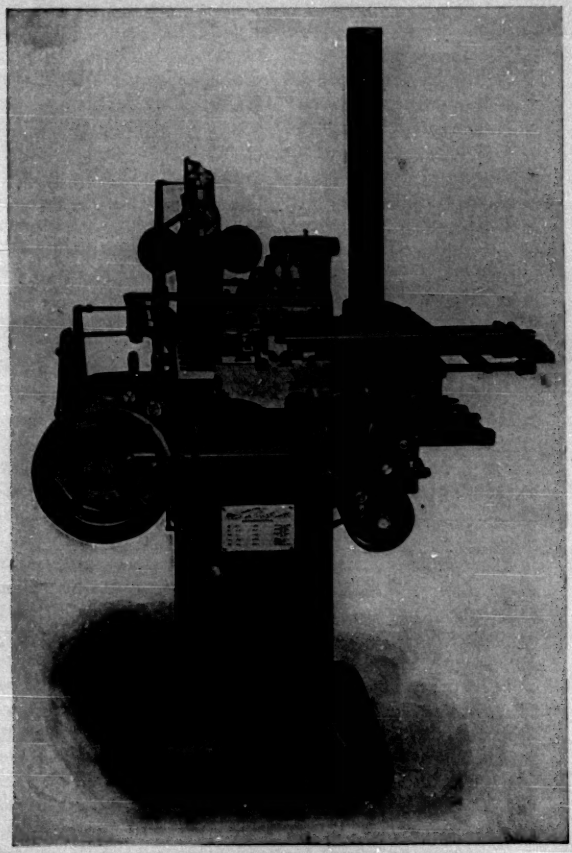

PLATE I.—FRONT VIEW MONOTYPE CASTING MACHINE.
Size: 36 x 42 inches, including galley.

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index hand. For each word-space the minimum number of units admissible for this spacing is registered on this mechanism. When the index shows to the operator that the accumulating types would fill a line so far that no additional syllable can be added, it also shows precisely how much space is required to fill the line. This space is distributed among the word-spaces, the number of which is indicated on a dial, by finding the addendum required for each space to fill the deficiency. The requisite division is accomplished, mechanically, by means of a table attached to the index, and the resulting quotient is recorded at the end of each line on the paper ribbon.

While a copy is thus punched, the ribbon is wound upon a spool, and, when placed into the type-making machine, it will enter that machine with the end of copy foremost, passing through it in a reverse direction.

The matrices of the type-making machine are located on a rectangular plate, in two sets of rows, intersecting each other at right angles, in precisely the same order in which the characters are placed on the key-board of the first machine. At every stroke of the machine this plate is caused to make a reciprocating motion in both directions, and each of these motions is so regulated that, on the return stroke, the movement is so limited that the desired matrix will be placed centrally over the mould in which the type is to be cast. To accomplish this a number of stops is provided in the path of each of the two movements, which are operated by compressed air admitted to the corresponding pistons through channels which are closed by the paper ribbon, except where this ribbon is perforated. The location of the perforations determines which of the stops is to be brought into operation, and thus commands the position in which the plate of matrices is retained immediately before the type is cast. By means of a wedge the movement of the plate regulates the variable width of the type-mould to correspond with the width required for the character.

The paper ribbon entering the type-making machine in a reverse direction, the record of the justifying addendum will precede each line. By a pneumatic device this record

is caused to adjust a wedge, which regulates the width of the mould for each word-space occurring on this line. By this means the proper length of the line is assured.

After the matrix-plate has been arrested in that position, which will place the required character directly over the type-mould, the matrix is more correctly centered than the pneumatic stops are able to do, by means of a taper plug entering into one of the conical centering-holes which are located on the reverse side of the matrix-plate, one opposite each matrix, and the molten type metal is injected into the mould. After congealing, the jet is cut off, the mould is opened, and the finished type is transferred, by an ingenious mechanism, to the galley, where it collects in the form of a column, and whence it is taken by hand to be made up into forms.

The investigating committee witnessed the operation of a machine at the printing office of *The Philadelphia Inquirer*, and found it to work exceedingly well.

The rapidity of the ribbon-punching machine depends on the skill of the operator; but since the number of punching machines need not correspond with that of the type-casting machines, the rapidity with which the former machine is used has no direct bearing on that of the machine proper. An expert operator can easily furnish ribbon in excess of the capacity of the type-casting machine. It is, indeed, contemplated to have the writers use the punching machine to enable them to turn in copy on paper ribbons, ready for the type-casting machine. The separation of the processes of making the ribbon copy and casting the type has obviously marked advantages.

The latter machine runs at a speed of about 110 strokes per minute. With the exception of a few strokes at the beginning of each line, each stroke produces a type. The capacity of the machine is stated to be between 4,000 and 4,500 ems per hour, and this capacity is self-evidently independent of the skill of the operator, whose function is that of producing the perforated ribbon.

Matter set up by this machine has the important advantage of admitting of subsequent corrections and alterations, being fully equivalent in this respect to matter set by hand.

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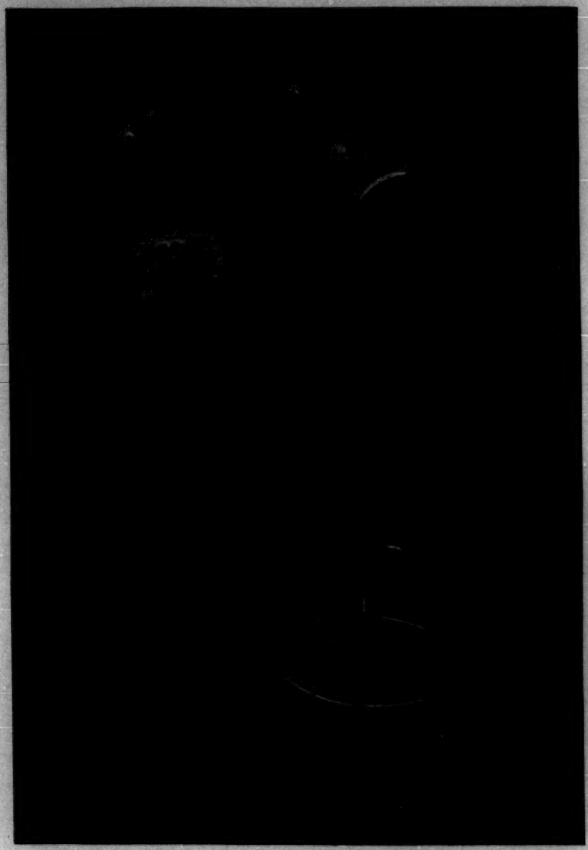

PLATE II.—THE LANSTON MONOTYPE KEYBOARD.

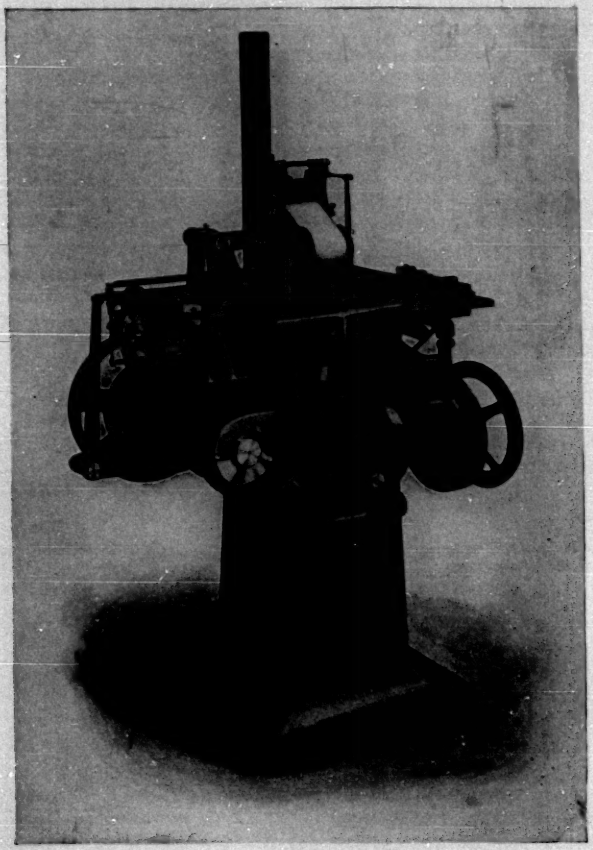

PLATE III.—REAR AND SIDE VIEW MONOTYPE CASTING MACHINE.

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This machine casts a perfect type in the ordinary sense of the word, which can be used in the finest magazine and book-work.

After the matter set by this machine has been used, it may be re-melted, or the type may be distributed and used in the ordinary way for hand-work. The waste product of this machine can thus be advantageously utilized.

The investigating committee considers this invention as one of the highest order and importance.

The Franklin Institute, therefore, awards the Elliott Cresson Medal to Tolbert Lanston, of Washington, D. C., for his monotype machine.

Adopted at the stated meeting of the Committee on Science and the Arts, held Wednesday, April 8, 1896.

JOS. M. WILSON, *President.*
WM. H. WAHL, *Secretary.*

G. MORGAN ELDRIDGE,
Chairman, Committee on Science and the Arts.

THE RELATIONS OF ELECTRICITY TO STEAM AND WATER-POWER.*

BY CHARLES E. EMERY, PH.D., of New York.

It is a common inquiry of late, by those who wish, in a general way, to keep in step with modern progress—will electric power be cheaper than steam-power? No general answer is possible. The cost depends upon the conditions obtaining at a particular place, and a discussion of the subject can only point out the nature of the conditions and illustrate their application by comparatively few examples.

Steady power is dependent upon some means of storing energy. For the steam engine the best storage is the coal itself. One ton of coal utilized through the organism of a steam engine is capable of practically exerting 1,120 horse-power for one hour. One ton of water, even if it have a fall of 100 feet, would exert no more power during such fall

*A lecture delivered before the Franklin Institute, March 27, 1896.

than the ton of coal falling through the same distance, or about one-tenth of a horse-power for one hour. Storage of water for power purposes is, therefore, only practicable in enormous natural reservoirs.

As yet, electricity is not a source of power, but a means of transmission which enables power to be generated where sources are available, and work to be performed where there is work to be done, and long transmissions are in general commercially desirable wherever transmitted power can be furnished at less cost than an equal power can be developed on the premises.

The facility of developing power in desired quantities where it is wanted has given steam-power a great advantage for many locations; but the great improvements in electrical transmission of recent years will do much to offset this advantage. It is now possible to utilize water-power in mountain fastnesses and at considerable distances from centers of trade and mechanical operations, and transmit it where the energy can be utilized. The industry has long since passed from the experimental stage, and the application to a particular case is a commercial question to be based on an estimate as to the cost of the installation in relation to the work to be done, rather than the practicability of accomplishing the purpose electrically.

The advance has taken place rapidly, but has, nevertheless, been thorough, so that there is no probability that there will be any material change in conditions in the future, and new applications will, in the main, be practically duplications of those already established. This arises from the fact that both of the general features of progress stated have about reached the limit. Electric machinery is now constructed on a business basis and sold for about the same price per pound of finished material as other machinery, the manufacturer depending upon larger sales for profit instead of higher prices, and patents have very much less influence on the result than in former times. The later apparatus has, moreover, as nearly reached the theoretical limit of efficiency as can be desired.

The principal improvements which have made electrical

transmission practical have been in the development of methods and apparatus which will permit the use of higher electrical pressures or electro-motive forces, than formerly. Formulæ based on Ohm's law show that a given amount of energy will be transmitted over conductors of a given size to distances proportioned to the squares of the electro-motive forces. That is, by doubling the E. M. F. the distance may be increased four times. For long-distance transmission the copper in the line is one of the most important elements in the cost, and the above considerations show that, to secure economy in copper, the voltage must be as high as practicable.

The electric pressure is limited by questions of safety and the use of particular apparatus; varying from about 50 to 127 volts for incandescent lamps, which is doubled, so far as transmission is concerned, by the use of the Edison three-wire system, in which part of the lamps are supplied at, say, plus 125 volts, and part at minus 125 volts, while the pressure between the outer wires, or about 250 volts, is used for larger electric motors. Electric railroads are usually operated at from 500 to 600 volts, which is about the limiting pressure which can be endured by human beings, though sufficient to kill a horse. Arc lamps are, however, operated in series, with a difference of potential at terminals of dynamo of 2,000 to 4,000 volts, so that such circuits are extremely dangerous.

It is assumed that it will not be necessary here to elaborately develop elementary details. Most of those present already know the difference between direct and alternating current, and realize the difficulty of generating direct current with high voltages. We will, however, call attention to the fact that alternating current is most advantageous for the electric transmission of power; first, from the fact that the current can be generated and utilized without the use of commutators and brushes, and, second, that alternating currents of a given pressure may be transformed into currents of other pressures, by the use of what are termed "transformers," without the use of moving parts of any kind.

Calling the circuit carrying the original current the "primary," and the parallel circuit the "secondary," the voltage in the secondary may be made any proportion of that in the primary by simply varying the number of turns in the coils, but the work done in each will be the same, less ordinary losses. For instance, 10 ampères at 100 volts in the primary will, in a secondary containing one-tenth the number of turns, give 100 ampères at 10 volts. This is called "step-down" transformation, because the pressure is reduced. If, however, the primary contains a fewer number of turns than the secondary, the pressure in the latter is increased, and it is called "step-up" transformation.

It should be noted that alternating current can be generated at a comparatively low voltage, or one which is safe to human life, and causes no difficulty with the insulation of the moving parts, and that the energy thus developed may, by step-up transformation, be transmitted with lower current and higher voltage to a distance where, by means of step-down transformers, a large current and low voltage may be obtained for lighting and power purposes.

Alternating current motors are of several kinds, such as "synchronous motors," very much like, and running in "step" with, the generators—that is, so as to pass the same number of poles in the same time,—which motors are preferred for large installations. With moderate powers, electric transmission is preferably made with what are called "polyphase currents," or several currents, in which the phases, or maximum E.M.F.'s, are not coincident. In "polyphase motors" of the "induction type" the armatures carry conductors short-circuited on themselves. The action of the alternating current in the coils of the magnets is to cause alternating magnetism to flow across the armature, thus inducing current in the conductors of the armature on the transformer principle, which currents are attracted by the field produced, and motion results.

The eddy currents, produced in a mass of metal subject to alternating magnetism, were early investigated by Prof. Elihu Thomson; but the first conception and practical carrying out of the idea that these currents—if localized by conductors inserted in the iron core of an armature—would be attracted

by the magnets generating them is, doubtless, due to Tesla, whose inventions on this subject are owned by the Westinghouse Company, and form one of the elements of value considered in the recent agreement between the General Electric and Westinghouse Companies in relation to the joint use of patents.

It is also possible to pass alternating currents in at certain points of the armature of an electric generator, and take direct current from the same armature, by means of a commutator and brushes, in the same way as from an ordinary direct-current machine. Such an apparatus is called a "rotary converter."

The application of these various devices for long-distance transmission would be, substantially, as follows: If the power were derived originally from a waterfall, the water-wheel would preferably be directly connected to an electric generator, forming what the speaker has called a "turbine dynamo," to correspond with the term "engine dynamo," so frequently used to designate apparatus consisting of a steam engine operating directly an electric generator. There should be a sufficient number of these turbine dynamos to furnish the current required with, at least, one spare unit, and, where practicable, all the power units in operation would deliver to main "bus-bars," or large electric conductors, in the station, and from the same to step-up transformers, which would raise the E.M.F. and reduce the current transmitted, thereby reducing the amount of copper required for transmitting the energy to a distance. For instance, the electric current may originally be generated at 2,000 volts, be raised by transformation to 10,000 volts or upward, at which pressure it may be conveyed many miles to points on the high-tension lines, and branched to points where the work is to be done, when, through step-down transformers, the pressure would be reduced to suit such work. For instance, one bank of transformers could reduce the alternating current to about 350 volts effective pressure, or about 500 maximum, and the current be transmuted by means of a rotary converter into direct current at 500 to 550 volts, and employed to operate electric railroads, the rotary transformer taking the place in the local station of the

boilers, engines and generators required for operation by steam.

In another case step-down transformers would be employed to reduce the pressure to 2,000 volts—for instance, on entering a city—and a local distribution circuit would be established at this pressure, which in turn would supply transformers at different parts of the city; for instance, in a building where considerable power is required, or at one point in a block where there are a large number of small consumers, the reduction for power purposes being generally to 500 volts, or to suit the motors employed, and for lighting purposes to 50 or 100 volts to suit the lamps installed. Synchronous motors could be operated at the full pressure of 2,000 volts from the distribution lines. At other points local stations would be established to supply three-wire city distribution. In other cases arc lights would be supplied from the high-tension current, the circuit for several lamps being supplied from one transformer; but in many cases a small transformer would be provided for each light. Cut-outs would, of course, be located in all the branches, and, in a low-tension system for local distribution, regulators would be placed to maintain a uniform voltage on each of the circuits.

The cost of steam-power depends upon the fuel consumed, the cost of the labor, supplies and repairs, together with interest on the investment and a contribution to a sinking fund, which will renew the plant in twenty to twenty-five years. The cost of fuel depends upon the kind of engine, which varies the quantity of water which must be evaporated into steam in order to supply such engine; also upon the kind of boiler, which varies the amount of water which will be evaporated per pound of fuel. There are so many conditions affecting the problem that separate calculations must be made for each case, or the probable result be inferred by consulting a number of large tables formed by progressively varying some one or more of the important conditions.*

* See tables of the writer in *Trans. Am. Soc. C. E.*, Vol. XII, p. 425, November, 1883; *Trans. Am. Inst. Elec. Engrs.*, Vol. X, p. 119, March, 1893; *ibid.*, Vol. XII, p. 464, June, 1895.

At this time we can only present briefly the calculations required for a single case.

Let it be supposed that 250 horse-power is to be delivered from a compound condensing-engine to a jack-shaft at higher speed. We assume that the friction of the apparatus as a whole will be 10 per cent., so that the mechanical efficiency is 90 per cent. All calculations are based on the indicated horse-power, or that measured by the indicator in the cylinder of the engine. Such indicated horse-power must, therefore, be 1 ÷ ·9, or 1·111 times the net horse-power. We assume that the engine requires 18 pounds of water per indicated horse-power per hour, and that the boiler will evaporate regularly 8½ pounds of water per pound of coal. The former quantity is larger than shown by some experimental results, but all that can be depended upon in regular work for variable power. The quantity last named is smaller than obtained experimentally, but fully as high as can be secured under average conditions. On this basis it will be found that, with coal at $3 per ton of 2,240 pounds, the cost of coal per net horse-power per hour will be 0·3465 cent. In manufacturing neighborhoods the cost per net horse-power hour for labor will be 0·17 cent, and from observation it is known that supplies and ordinary repairs will cost approximately 0·09 cent. If we allow for sinking fund, taxes and insurance 5 per cent. of the total cost of the apparatus, and also 5 per cent. for interest on the money invested, the cost per net horse-power per hour for this item will be about 0·2078 cent. The total cost per net horse-power per hour for coal, labor and supplies will, therefore, on this basis be 0·607 cent, and with fixed charges for interest, etc., added, be 0·815 cent, or for a year of 3,080 hours, $25.18. Similarly proceeding for an ordinary non-condensing engine of 10 horse-power, for which the whole of one man's time would not be required, the cost of the power will be found to be much larger, or about 2·45 cents per net horse-power per hour, or $75.46 for a year of 3,080 hours. With triple-compound engines, with units of not less than 500 horse-power, and very careful attention, the power can be obtained at the rate of 0·7

cent per horse-power per hour, or $21.38 per year of 3,080 hours. For every hour in the year the prices for the 10 horse-power and 500 horse-power engines will become $215 and $61 per net horse-power per year, respectively.

In ordinary practice, and particularly with variable power like that required for electric lighting and power purposes, the cost with compound condensing-engines, which are the best available for such a purpose, will be practically 1 cent per horse-power per hour, or 1 "horse-power hour," as it is called, or $30.80 per year for 1 horse-power continued for 10 hours per day and 308 working days in the year. At this rate, if 1 horse-power were operated throughout the entire year, or 8,760 hours, such horse-power would cost $87.60 per year. If, however, the power were variable, the yearly cost would be made up from the sum of the horse-power hours. It is found in practice that, by summing together the horse-power hours developed in ordinary electric lighting and power plants, the sum is in general not greater than if the maximum power were operated during ten hours per day for 308 working days, or, say, 3,080 hours per year. In this case each average horse-power would cost $87.60 per year, and each maximum horse-power $30.80 per year; but the average horse-power would be to the maximum horse-power as 3,080 to 8,760, so the total cost for the year of the entire power used would be the same as if the maximum power were employed for the shorter time, or the same as for what is called ten-hour power. We shall have occasion to refer to this point more at length in connection with the charges for water-power.

The cost of a water power on streams reasonably free from ice and floating obstructions is due principally to the interest on the capital invested. Where the work is on a large scale, money can generally be raised for 5 per cent., and in making the calculations it is customary to include, in addition to this, 2½ per cent. for a sinking fund, 1½ per cent. for repairs, 1 per cent. for taxes and incidentals, or a total of 10 per cent. on the cost, with about 75 cents per horse-power for attendance, oil, etc. On this basis water-

power has been developed at a number of points in different parts of the country at a total cost corresponding to an annual charge of $8 to $12 per horse-power year. On the contrary, the water-power on the Merrimac, calculated on the same basis, has apparently cost about $30 per horse-power per year, or practically the same as steam power; but this cost includes certain rentals, which are in the main returned to the owners through the water-power company, which is itself owned by the mills, for which reason—and the fact that the real estate investments have been very remunerative—the actual cost of the power is considerably less than the apparent cost. It is, however, a fact that cotton mills can be operated profitably by steam-power without water-power, as shown by the considerable number of mills at Fall River and New Bedford, Mass., and elsewhere.

This preliminary discussion of the available facts will be of assistance in an examination of the outlook for companies incorporated to develop water-power and distribute the same electrically. The desirability of employing electricity for transmission to a distance is evident; but the decision of a number of eminent experts, in relation to the enormous developments of power proposed by the Cataract Construction Company at Niagara Falls, was that it was cheaper to distribute power locally by means of electricity than by the use of ordinary mechanical methods, and that the transmission of power to a distance could be part of the same system. In carrying out these views, units of 5,000 horse-power were adopted, each consisting of an electric generator and a direct-connected turbine of sufficient size to operate the same.

The cost of the work at Niagara Falls is not known to the speaker; but, continuing the discussion on general principles, it may be stated that, when the electric distribution of a very large power is undertaken, there are numerous distinctive features which reduce the cost. Work done on a large scale is cheaper as a general rule, and, moreover, the system of massing a number of large power units in one location makes it possible to do the work with one head-

race, one tail-race, and one series of wheel-pits, arranged in a single building. Under these conditions, it is thought that the hydraulic development for 80,000 to 100,000 horse-power—to include head- and tail-races, head-gates, wheel-pits, wheels and mechanical means of transmission from the wheels to the dynamos, together with necessary buildings, water rights, promotion expenses and the land needed for the work, independent of investment in extra property—should not cost more than $30 per gross horse-power, or $42.75 per net horse-power delivered. It is probable, however, that, to secure capital for such an enterprise, the original cost, represented by the securities issued, would be considerably greater than that stated. Moreover, it would not be practicable to develop at once the whole of such an enormous power, though the principal portion of the expense would necessarily be incurred at the outset. These considerations might raise the cost of a plant to $80 per net horse-power delivered.

At present prices it is considered that the cost of local electrical transmission will not exceed $40 per net horse-power. The total cost of plant would then, on this basis, be $120 per horse-power, and, allowing interest and fixed expenses as before, and $1.50 per horse-power for running expenses, would make the yearly cost $13.50 per horse-power. With the cost price as low as this, the power company might afford to sell at a profit power for $15 to $18 per year per net maximum horse-power, and the advantages to consumers would be very apparent, compared with twenty-four-hour steam-power, every hour in the year, for $61 to $88 per horse-power; or even ten-hour working-day steam-power at $30.80; or for coal at $1.50 per ton, say, $25 per horse-power per year.

Long-distance transmission in large units differs only from local transmission in requiring the employment of longer electrical lines and the use of step-up and step-down transformers previously referred to. The double set of transformers in large units will only cost about $11 per horse-power, and for a transmission of 20 miles at 10,000 volts, the copper in the line will cost about $21.50 per horse-

power. The total cost of the hydraulic and electrical development should not exceed $150 per horse-power delivered; so, calling the cost of attendance $2.50 per horse-power, and deducing the interest and fixed charges as before, the yearly cost would be only $17.50 per horse-power. Promotion expenses, the interest accumulating on bonds during construction, and other expenses incident to financing a large operation of this kind, would probably increase the cost greatly; still it would appear that the transmitted power might be sold for $20 or, at least, $25 per net horse-power in large units along the high-tension lines, which would still show an advantage over steam-power developed with coal at $3 per ton, and, at the worst, would stand on an equal footing with ten-hour steam-power developed in large units with coal at $1.50 per ton, as above stated.

Everything considered, it may be assumed that prices will be adjusted so as to make it advantageous for large consumers to use the power, and for high-tension lines to be run to their premises for that purpose. In a large city, however, it is not practicable to run high-tension lines except underground, and in connection with lines at lower tension, so that the distribution becomes complicated, and, without great care, quite dangerous. Two methods of distribution would be practicable—one to reach the power-houses of companies already installed and utilize their lines; the other to transmit the power locally through lines at lower tensions, though much higher than have been employed until quite recently. For instance, the 10,000 or 20,000 volts used for transmission could be transformed down to 2,000 volts, and these lines distributed to various points in a manner already described, to furnish current through other transformers for power and lighting purposes. If such distribution be attempted through companies already installed, as first assumed, their plants have already cost several times as much as we have estimated for the entire transmission plant, and interest and dividends must be paid on the whole capital invested; consequently, a saving of $5 or even $10 per horse-power would not be so large a proportion of the necessary total cost, including interest,

as to make a great difference in the charges to small consumers.

The attempt to establish a new distribution in a city already containing local companies for the same purpose, would necessarily meet with opposition, and, if forced through, the cost of making the distribution in the most economical way would be so serious that power in small quantities would still be so expensive that a very large use could not be predicted, in competition with ten-hour steam-power where coal is less than $3 per ton.

It is improper to calculate that all the power available can be sold at the prices now charged by the electric lighting companies, or for from 4 to 6 cents per horse power hour instead of 1 cent for large engines and 2½ cents for small ones previously mentioned. Such companies necessarily charge large prices, principally on account of the large amount of capital invested and large operating expenses, independent of the cost of coal, and such prices are advantageous to small consumers from the fact that the power supplied is convenient, always available on demand, and costs nothing during periods of disuse. It is true that the uses of power are greatly extending in the larger cities, even at these prices, but the applications are generally in very small units, and the whole output for this purpose is very limited compared to the total amount of power used in the city, the majority of which cannot be reached without reducing prices nearly as low in some cases, and in others lower than the same work can be done by the steam engine. In making the comparison, the use of the steam plant, and particularly of exhaust steam in winter for heating purposes, must be considered.

These remarks apply principally to ten-hour working day power, or variable power for which the mean is a moderate fraction of the maximum. For steady power during twenty-four hours, the regular local companies could afford to make large reductions, and a special power branch of an electric transmission company give very satisfactory prices, for the reason that the number of hours' service does not increase the cost of water-power, whereas, the cost of steam-power is

practically proportioned to the number of hours it is used. Even, however, if the transmission company obtained prices approximately as high as are now charged by the electric light companies for very small powers, and made rates which appeared reasonable for twenty-four-hour power, it would still be unable to give satisfactory prices to the large amount of ten-hour power which goes so far in making up the aggregate, for the reason that it costs the transmission company practically as much for ten-hour power as for twenty-four, and charges must be made on that basis; that is, the transmission company could not reduce its price in proportion to the number of hours used, or sufficiently to compete with steam-power where coal is less than, say, $3 per ton. The same would be true for variable power continued through twenty-four hours when the average power is much lower than the maximum.

If the average powers during each hour be summed for the entire year, the horse-power hours for that time will, in most cases, be found not greater than if the maximum power were continued for ten hours per day during the working days in the year, as has already been stated. It follows, therefore, that the cost of the 3,080 horse-power hours, or for each horse-power per year, would, at 1 cent per horse-power hour, be only $30.80 per year, and, therefore, the charge for water-power, although available every hour of the year, must be sufficiently less than $30.80 per year to warrant the change.

It is interesting to note that these facts have been put in an entirely different shape, by publishing only the cost of average power, when the charges for transmitted water-power must necessarily be based on the maximum power. If the total cost of variable power be divided by the average horse-power throughout the year, the cost for each average horse-power will necessarily be very much greater than for each maximum horse-power, for the reason that the average horse-power is much less than the maximum power, and the prices of the two must be inversely proportional to each other, though the total cost remains the same. As stated, the cost of 1 horse-power for 308 days of ten hours each, at 1 cent per horse-power hour, is $30.80, and if the power

were continued for every hour in the year it would be $87.60. The larger amount is 2·844 times the smaller, and the smaller 35·2 per cent. of the larger. For variable power with the average 35·2 per cent. of the maximum, the cost of each average horse-power would be 2·844 times as much as for each maximum horse-power, or $87.60 per horse-power per year; but, on the other hand, the maximum horse-power, which is 2·844 times the average, would only cost for each horse-power 35·2 per cent. of the average horse-power, or $30.80 per year; so the total cost per year, found by multiplying the lower power by the higher price, or the higher power by the lower price, will be exactly the same.

In the published account, previously referred to, only the very high prices based on the average horse-power per year are given, or those which correspond to the $87.60 in above illustration; whereas, the lower prices are the ones applicable, corresponding to $30.80 in the illustration given. The ratio of the average to the maximum power, or 35·2 per cent. in the above case, is called the "power factor." If such power factor were only 20 per cent., the cost of the average power would be five times as great as that of the equivalent maximum power; but as there would be only 20 per cent. as much power to pay for at the higher rate, the cost would necessarily be the same as if the maximum power were continued one-fifth of the time, and the cost of steam-power would evidently be only one-fifth of the cost of that continued for every hour in the year. The price of water-power must evidently be low enough to meet this cost, though actually available five times as many hours in the year.*

It may be necessary for a power transmission company to sell electric power by meter, but in such case the charge

* The calculations above presented are well illustrated by a contract recently made by the Cataract Construction Company with the Buffalo Street Railway Company. (See *Elec. Engr.*, August 5, 1896, p. 133.) The railway company is to be furnished 1,000 horse-power day and night for $40 per horse-power per year, and apparently pays $4.50 per horse-power for apparatus, making the total cost on basis stated in text $44.50 per horse-power per year. If 1,000 horse-power of steam is actually used every hour in the year, it would cost, at 1 cent per horse-power hour, as stated in text, $87.60 per horse-power per year, so the railroad company has made a good bargain even if 1,000

must be increased in the proportion above indicated, or 2·844 times in one illustration and five times in the other, making the result the same as if the maximum power were charged for. It is true that on electric light circuits it has been found that the plant need not be increased in as great a proportion as the increase in rated power of motors installed, for the reason that all are not operating at maximum power at the same time, so it would be possible for a power transmission company to make allowance for this in fixing prices. With the larger demands for variable power this could not take place. For instance, in the afternoon of a dark day the electric lighting plants and the electric railroad plants would both demand practically maximum power at about the same time. Moreover, the power factor of 35·2 per cent. is about that found in practice with large motor loads, as determined by the electrical output, so that the low average power of a large number of motors is already included. Consequently, with this power factor the hydraulic, generating and transmitting plants must be 2·8 times as large as would be required for average power, and the interest on the cost, which principally regulates the charges, be increased accordingly. With steam plants there is not so great a discrepancy, for the reason that the whole apparatus can be forced above capacity for a short time during the peak of the load, whereas the capacity of a water-power plant can only be increased by increasing the capacity of the wheels, and, consequently, of the whole hydraulic plant.

In conclusion, it may be stated that the investigation shows:

(1) That a very large water-power may be developed and

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horse-power is not used all the time. Additional power is to be furnished for $36 per horse-power, equivalent to $40.50, with fixed charges added as above. The load of the railroad, less 1,000 horse-power, must show a very low power factor; but if it be as high as 35·2 per cent., this represents, as explained in text, a cost for steam-power of only $30.80 per year per maximum horse-power, showing, as stated in the paper and emphasized in the conclusion of the first part, that 24-hour power can be furnished advantageously by transmitted power, but that questions arise for 10-hour power or variable power of an equivalent number of horse power hours.

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ERRATUM.

Foot-note below should read as follows:

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the power transmitted locally with advantage, in competition with steam-power, even where fuel is cheap, if the cost of construction be kept within reasonable limits.

(2) That transmission of power 20 miles from a waterfall is practicable, even in competition with steam-power from cheap fuel, if the power is utilized for twenty-four hours, or in large units, or delivered at high tension on the premises of the manufactory and distributed under conditions less exacting than those which obtain in a large city.

(3) That when fuel is $3 per ton or over, electric transmission is very generally applicable.

The lecture was illustrated with a large number of lantern slides, showing the distinguishing features of electrical transmission installations in different parts of the country. The speaker stated that the business was advancing with rapid strides, and that the future growth was very promising.

The speaker continued: It is considered impossible within reasonable compass to even give a list of the principal plants of this kind, but brief references will be made to a few of the same for the purposes of illustration.

The possibility of electric transmission of power was foreseen by very many parties in different parts of the world, and some comparatively unimportant applications were made from time to time, but an historical work would be necessary to give the same proper credit. The growth of the business as a commercial industry practically began with the Electrical Exposition at Frankfort, in 1891, where electric energy was transmitted from a waterfall at Lauffen, 108 miles away. The cost of this particular plant was so great that the power developed at Frankfort really cost some four to five times as much as it could have been developed for with steam machinery on the spot; but the installation settled a large number of doubtful questions and warranted the application of such transmissions in evidently favorable locations, thereby bringing about a reduction in the cost of apparatus and opening a wide field for such enterprises.

The Westinghouse Electric and Manufacturing Company are understood to have installed the first commercial long-distance transmission in this country, and this firm has carried out works of the largest magnitude that have been undertaken in any part of the world, as instanced by the 5,000 horse-power biphase alternating generators at Niagara Falls. The General Electric Company has probably been doing the greater volume of business during the last few years.

The Westinghouse Company, about the year 1890, or before the Frankfort Exhibition, arranged to light the city of Portland, Ore., by power generated at the falls of the Willamette River, at Oregon City, 14 miles distant. The fall is about 40 feet. Victor wheels of 300 horse-power, through intermediate shafting, operate two alternating-current dynamos. The current generated at 4,000 volts is received in Portland at 3,300 volts, and reduced by transformers to 1,100 volts for distribution through the city to ordinary transformers, by which it is reduced to 50 to 100 volts.

Another early plant installed by the Westinghouse Company was at Telluride, Col., where power is furnished the Gold King Mill from a waterfall nearly 3 miles distant, but on the other side of a mountain 2,500 feet high. In this case a Pelton wheel, receiving water through a 2-foot steel pipe, under a head of 320 feet, drives an alternating-current generator, which in turn operates an alternating-current synchronous motor of 100 horse-power at the mill. The pressure is 3,000 volts.

The Westinghouse Company has also a single-phase transmission plant in the mountains at Bodie, Cal., where the ruling price of wood has been $10 per cord for years. Sufficient water is obtained from Green Creek, on the north slope of one of the spurs of the Sierra Nevadas, to operate, at a head of 355 feet, four 21-inch Pelton water-wheels. The transmission is made at 3,530 volts, without transformers, to a distance of 12½ miles. At present only one 120-kilowatt synchronous motor has been installed.

The same company has an interesting plant at Pomona,

Cal. It consists of a Pelton water-power plant and a Westinghouse single-phase alternating-current transmission plant, in which the generators supply current to step-up transformers, raising the pressure to 10,000 volts, and transmitting current on separate circuits to Pomona, 13¾ miles distant, and San Bernardino, 28¾ miles distant, where the pressure is reduced by transformers to 1,000 volts for local transmission, and finally to lower pressures to supply incandescent lamps. The water is supplied through a pipe 30 inches in diameter and about 2,000 feet long, which has sufficient capacity for 1,882 horse-power at 390 feet head, only about one-third of the power being at present required. The efficiency of this transmission is over 75 per cent., and, experimentally, the two lines have been connected so as to make a circuit 85 miles in length, corresponding to a distance of transmission of 42½ miles, which distance is greater than has yet been covered by any transmission since the Frankfort experiments. The efficiency over this long line proved to be over 60 per cent.

One of the earlier installations of the General Electric Company was at Taftsville, Conn., where the Ponemah Mills are driven electrically by power from water-wheels at Baltic, 4½ miles distant. The electric plant consists of two 250-kilowatt three-phase generators, and two 250-kilowatt synchronous motors, wound for 2,500 volts.

At Columbia, S. C., there is a local electrical transmission plant, the turbines and generators being situated in a gorge and the mill on a bank near by. Victor turbines connect directly, through horizontal shafts, to two 500-kilowatt General Electric three-phase generators, which, on account of the low head of water, are built to operate at a speed of 108 revolutions per minute, and, consequently, are of colossal size, each weighing 10,000 pounds, with armatures 10 feet in diameter. In the mill there are sixteen induction motors of 65 horse-power each, severally hung from the ceiling, and driving separate sections of line shafting. The speed of the motors is 535 revolutions per minute.

The General Electric Company has erected a transmission plant at Lowell, where three-phase generators, operated

by water-power, furnish alternating current to sub-stations 9 and 15 miles from the power-house, from which direct current is delivered to operate the railway system between Lowell and Nashua. The transmission is at 5,500 volts, which in the sub-stations is reduced in potential by transformers, and supplied as direct current to the trolley lines, at 550 volts, through rotary converters.

The same company has installed, at Portland, Ore., three 450-kilowatt three-phase generators, with armatures mounted on vertical shafts, each of which can be connected directly to a turbine operating the same at 200 revolutions per minute. These turbines can, however, be disconnected, and larger ones connected by belt during high water, when the head is greatly decreased. Current is generated at 6,000 volts, which is transmitted the whole distance, and at a local station at Portsmouth, is, in part, transformed down and used to operate two 400-kilowatt rotary converters, which furnish current at 500 volts for operating street railways. Light is also furnished and motors operated on the Edison four-wire system.

The General Electric Company has also made a very interesting adaptation of three-phase transmission to operate the Silver Lake group of mines, lying about 4 miles southeast of Silverton, Col., at an elevation of 12,300 feet above the sea. The mill was formerly operated by steam-power, coal being brought by a zigzag track up the mountains, and, by the time it reached the furnace, cost $8.75 per ton. The plant is now operated by water-power brought from the Animas River, above Silverton, by a 3 x 4 foot flume 9,750 feet in length, which carries 2,350 cubic feet of water per minute. The head of water is about 180 feet, which is used to operate two double-nozzle Pelton water-wheels, 4 feet in diameter, in a small building in the valley below. The conductors are No. 3 B. & S. bare copper wires, supported on a pole line extended up the mountain passes for 3 miles through the rugged country, spanning at one point a distance of 275 feet across a chasm. The transmission is made at a pressure of 2,500 volts. About three times as much power is now available as when the

steam engine was employed, so that the change has been a great improvement in efficiency and economy.

A notable transmission system has recently been completed to supply light and power at Sacramento from Folsom, on the American River, 24 miles distant. The State, mostly with prison labor, developed the water-power, the water being first used for power purposes in co-operation with the Sacramento Electric Light and Power Company, and then for irrigation. There is a massive dam of granite, 650 feet long, 89 feet high in the center, 87 feet wide at the base, and 25 feet wide at the crest, with flash-boards 6 feet high, which, at high water, can be lowered in a recess in the crest of the dam, and raised when desired by hydraulic pistons. The water is conducted in a canal 2 miles long to the power-house, where a fall of 55 feet is available. There will be installed four pairs of wheels of the McCormick horizontal shaft turbine type, each pair of 1,260 horse-power at 300 revolutions. Four General Electric three-phase 750 kilowatt generators are operated at 800 volts, which is raised to 11,000 volts through step-up transformers, each of 265 kilowatts capacity. The sub-station is centrally located in the city of Sacramento, and contains step-down transformers and 1,000 horse-power in three synchronous motors. These motors drive arc lighting and railway machinery. The power is distributed through the city by a low-tension three-phase four-wire Edison feeder and main system, the potential regulators being located in the sub-station. Street cars in Sacramento have been operated by transmitted power since July 14, 1895.

The Niagara Falls hydraulic and electric plant, with which the honored Chairman of your Lecture Committee, Dr. Coleman Sellers, has been so prominently connected, is notably much the largest that has yet been undertaken, it having been decided, as previously stated, to use the entire power developed for the generation of electric current, and operate all local manufactories, as well as those at a distance, by electric transmission. The arrangement is distinctive, as the water, instead of being conducted in a canal to a power-house and discharged at a low level directly, is received by

the turbines in a deep pit about a mile back of the falls, and discharged through a tail-race tunnel extended northward under the village of Niagara Falls, and coming out of the bluff near the lower water level. Each unit is 5,000 horse-power, or larger than either of the entire plants previously referred to. It is intended to instal ten such units in the first wheel pit, though the tunnel has sufficient capacity for about 100,000 horse-power. The head utilized is about 140 feet.

The turbines were designed by Messrs. Faesch & Pickard, of Geneva, Switzerland, and built by I. P. Morris & Co., Philadelphia. They operate at 250 revolutions per minute. The governor was designed by the same parties. The turbines are necessarily near the bottom of the pit, and are connected with the head-race by steel penstocks. The generators are at the ground level, and are connected directly with the turbines by steel shafts made up of tubes 38 inches in diameter, reduced to 11-inch solid shafts at the journals. To secure regulation, a heavy fly-wheel is necessary to give the governor time to act. A separate fly-wheel was made unnecessary by the suggestion of Mr. Forbes, the consulting engineer, of England, that the fields of the generators be made to revolve instead of the armatures.

The generators were designed and constructed by the Westinghouse Electric and Manufacturing Company. The revolving field consists of a heavy steel ring, 11 feet 6 inches in diameter, with internal pole pieces and bobbins, connected by means of an upper disc with the shaft which extends through and above the stationary armature. The generators deliver biphase alternating current at 2,000 volts, with a periodicity of twenty-five cycles per second.

The total weight of the revolving parts is 152,000 pounds, of which about 79,000 pounds are included in the revolving field above referred to. This enormous weight is practically balanced by the water-pressure, the remainder being supported in an ordinary collar thrust bearing. Twin turbines are employed. The lower disc of the case carries interior guides for the lower turbine, which latter is supported outside the guides by a revolving disc below, receiv-

ing no pressure, while the upper stationary disc for supporting the guides for the upper turbine is perforated and permits the water-pressure to reach the under side of the revolving disc carrying such turbine outside the guides. In this way the greater part of the load, and, at times, the whole of it, is water-borne and the thrust bearings only receive the residual up or down strain. The gates are ring-shaped, and are moved up and down outside the discharge openings of the wheels by the governor, an arrangement not used or favored by turbine manufacturers in this country, though apparently operating satisfactorily in this case.

Water for power is supplied through two wheels of 1,100 horse-power each to the Niagara Falls Paper Company, and discharged into the tunnel. About 2,000 horse-power is being electrically supplied to the Pittsburg Reduction Company, and used in the manufacture of aluminum, the bi-phase alternating current being transformed in four large rotary converters to direct current. The uses of power in this establishment is to be greatly increased. About 1,000 horse-power is supplied to the Carborundum Company, which manufactures an abrading material used as a substitute for emery. This process being a heating one, the alternating current is employed directly, being simply reduced in pressure by a special regulator and static transformer to between 100 and 200 volts. About 1,500 horse-power is also being furnished through rotary converters for the operation of electric railroads, and it is understood that other applications will soon be made. It is also anticipated that a large block of power will be transmitted to Buffalo for various uses in that city.

SOME RECENT WORK ON MOLECULAR PHYSICS.*

By Reginald A. Fessenden,
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My first thought on writing to your secretary that I would lecture on molecular physics, was that I should review briefly the more important of the recent advances in that branch of science, but I was not long in reaching the conclusion that this would be inadvisable. For, to those of my audience who might be specialists in that direction, the greater part of what I should say would merely be a *résumé* of the recent history of the subject, while, in order to make it interesting to those who were not, an amount of preliminary description would be necessary which would leave no time for touching on more than one or two points.

I have, therefore, thought it best that I should take up certain phenomena with which we are all more or less acquainted, namely, the behavior of those metals which are in every-day use, and show how certain theories of mine may be applied to explain them.

Some of the theories which I shall develop to-night are not yet universally accepted as articles of scientific faith. Therefore, they should be received with a certain reservation until further evidence confirms them. On the other hand, I should say that they need not be viewed with distrust; for in no case is any theory introduced which has not received the sanction of some at least of the foremost specialists in whose field it belongs.

This subject, the molecular physics of solids, is one to which I have devoted special attention, and to which I have contributed some original work. I trust that I shall be able to bring to your notice certain new relations which will interest you, and which may help to give a more com-

* A lecture delivered before the Franklin Institute, February 14, 1896.

plete realization of the atomic theory of matter—relations which are, moreover, of great practical importance.

To begin at the beginning, we should commence with the ether. That subject is now so buried beneath a pile of mathematical theories, each one incompatible with observed facts at some one or more points, that I shall not disturb it to-night, but confine myself strictly to the atom and molecule.

First, let us try to get a more or less exact idea of the manner in which solid bodies are built up from atoms; how far apart, and in what manner, the atoms are spaced; how they are arranged; and the nature of the forces acting between them.

A description of the methods by which the diameter of the atoms has been calculated has, for so long a time, formed a portion of our text-book and lecture knowledge that I will not go over the ground again, but will simply give a list of the more important determinations of this constant. These are:[1]

Heat of combination of copper and zinc, 10^{-8}.

Heat of vaporization and surface tension of water, $\cdot 7 \times 10^{-8}$.

Viscosity of gases, 6×10^{-8} to $2 \cdot 9 \times 10^{-8}$.

The mean is about 10^{-8} centimeters, and in our calculation we will take the distance between the centers of two atoms of silver (the silver being in the solid state and at ordinary temperatures) as 10^{-8} centimeters.

The next question is: "How much of this space is occupied by the silver atom itself?" From Van der Waal's equation, which, though it is not exact, seems to give a fair

[1] It will be noted that I have rejected determinations depending upon measurements of the dark space in soap bubbles. This is for the reason that I do not consider them of any value for the purpose. The assumption made that the conductivity of a film is proportional to the thickness, even when the film is but a few molecules, or even only 1 molecule, thick, I regard as extremely improbable, and, indeed, it is possible to prove that it is incorrect. In fact, it is my opinion that one of the greatest hindrances to the development of molecular physics has been the undue importance which has been attached to some mathematical theories, based, so far as they have a foundation, upon surface-tension experiments.

approximation to the facts, we find that when a substance is at the critical temperature and volume, the space which the atoms would occupy if they were all touching each other is one-twelfth that occupied by the substance; consequently, the distance between centers of adjacent atoms cannot be more than 2·3 times the diameter of the atoms themselves. But below the critical temperature, the coëfficient of expansion is very great, so that the atoms in the solid state must, at ordinary temperatures, be much closer than this. In fact, if we take the values of the density of the molecules of alcohol, ether, carbon disulphide, etc., as calculated by Nernst, and compare them with the densities of the substances themselves in the fluid state, we find that the ratio of the volumes is only one-third instead of one-twelfth; *i. e.*, the distance between centers of molecules is only 1·5 times the diameters of the molecules. Taking into account the still farther contraction in passing into the solid state, we find that it is improbable that the distance between centers is more than ·3 times the diameter of the atom.

Again, starting from the solid state, if we consider the experiments of Dewar, we see that the electrical resistance of metals varies with temperature in such a manner as to probably become zero at the absolute zero of temperature. Both electrical resistance and expansion vary very roughly, linearly, with temperature; and the expansion for most of the metals between absolute zero and their melting points is, so far as we can judge, about 2 per cent. linear. Unless, therefore, we are prepared to make the supposition that the relation suddenly changes at low temperatures, we must suppose that there is no very sudden change of large amount in the coëfficient of expansion of metals near absolute zero.

Consequently, we see that the mean distance between centers of adjoining atoms is probably between 1·02 and 1·3 times the diameter of the atom itself. In other words, the distance between any two atoms is between $\frac{1}{50}$ and $\frac{3}{10}$ the diameter of the atom itself.

There is one difficulty, however, in accepting this conclusion. This is the fact that two substances can combine to

form a new substance which is smaller than either of its constituents. For example, if we add to 45·4 cubic centimeters of potassium its chemical equivalent of chlorine, which would by itself occupy about 18 cubic centimeters, we get as a product an amount of chloride of potassium occupying but 37·4 cubic centimeters, 15 per cent. less than either. This, at first sight, is very astonishing, and many theories have been suggested to account for it; such, for instance, as that the atoms are capable of existing in more than one state, and that the size

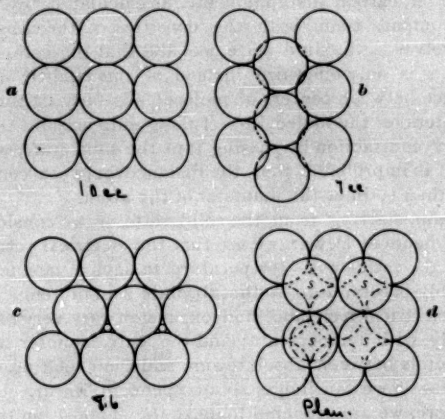

FIG. 1.

of the atoms in one of these states may be half or a quarter the size it has when the atom is in another state. No such hypotheses are needed, however, for the results follow, as I shall shew, from simple geometrical considerations.

Suppose we have a metal bar made up of atoms, and the metal is thoroughly isotropic, and does not split more easily in one direction than in any other. Then the atoms must occupy relative positions as shown in *Fig. 1a;* for if they were arranged differently, the bar would show cleavage planes. If, however, we roll it under great pressure, then the atoms

will be forced to take up positions as shown in *Fig. 1 b*, and it is now stronger in one direction than in another, and it is readily seen that the space occupied by the metal is now only

$$1/\overline{\tfrac{1}{2}},$$

or 70 per cent. of what it was before. It is, of course, impossible for us, in practice, to increase the density of a metal to this extent, for the metal flows with such great pressure; but this is the theoretical limit.

In the spaces, *s s*, here (*Fig. 1 d*) there is still left room for an equal number of atoms having a diameter $\frac{4}{10}$ that of the potassium atom.

Thus, we see that potassium could combine with an equal number of atoms of a monovalent element having an atomic volume 3, to form a new compound having an atomic volume of only 31·7. Therefore, instead of the contraction experienced in the formation of KCl being so great as to necessitate a new theory, postulating novel and remarkable properties of the atoms, we see that we might be prepared, from simple geometrical considerations, to find potassium compounds showing still greater contraction than is actually observed.

The actual contraction experienced in the formation of KCl can be accounted for by making the supposition that the atomic volume of chlorine is 18. The lowest atomic volume thus far measured is 21, at — 80°, but this was in the liquid state, and in the solid state it is probably less. Moreover, examination of the curve of atomic volumes and weights leads to the same conclusion.

I have elsewhere[2] calculated the theoretical shrinkage of NaOH, KOH and NaCl, and find that in all cases it comes within 5 per cent. of that actually observed, and is always on the right side.

This fact leads us to a very interesting result.

These calculations were made upon the supposition that the volume occupied by an atom is spherical. The fact that the calculations come out so closely seems to show that

[2] *Science*, March 3, 1893.

whatever the actual shape of the atoms themselves, the space which one atom occupies to the exclusion of another atom cannot differ very greatly from a sphere. When we reflect that each atom, when not at absolute zero, keeps other atoms from touching it by virtue of its kinetic energy, and that this repulsive force must therefore be exercised in all directions, we have a reason why this should be so.

In all my work on molecular physics I do not think I ever came across anything which gave me so vivid a sense of the actuality of the atoms as this fact, that the observed contractions in the case of these salts is just what it would be if the atoms were arranged as solid bodies, nearly touching one another, and of approximately spherical shape.[3]

This same tendency of the atoms when stressed to assume an æolotropic state is the chief reason why, so far, we have been unable to obtain any accurate data upon which a complete theory of matter could be founded. I do not think it is generally appreciated how inexact is our knowledge of the physical constants of solid bodies. There are very few constants, indeed, as will be seen from the tables, given below, *Fig. 8*,[4] which we know to within 20 per cent. This is because these constants depend largely upon the physical manipulation which the material tested has undergone. Even winding a wire on a reel will, in some cases, markedly change its electrical conductivity, as dynamo builders are aware, and the difference in tensile strength of hard-drawn and annealed material is too well known to need emphasis.

It was Mathiessen, I believe, who first pointed out that a wire which had been drawn several times was no longer

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[3] I have since made up a few crystals by piling together small paraffine balls, whose sizes were proportional to the sizes of the atoms in the crystalline substance, the different sizes of balls being used, of course, in the same proportion as the corresponding atoms in the substance. In each case the angles thus determined experimentally were very close to those of the actual substance.

[4] The variations in the tensile strengths are not given, as they depend so largely upon the size of the piece tested and on other circumstances mentioned below. The difference amounts in some cases to 200 per cent.

a solid cylinder, but really a nest of concentric tubes. *Fig. 2* shows two sections of such a wire.

It is possible, I understand, in certain cases where a wire has been drawn a number of times without sufficient annealing, actually to peel off these tubes one after another like the coats of an onion.

Mathiessen also supposed that, in drawing, the inner tubes were sometimes broken while the outer ones still held, and accounted for some anomalous results he had obtained by this theory. The reason of this curious formation is less known than the fact. It is evidently due to the piling up of the stress at certain points. This is analogous to the

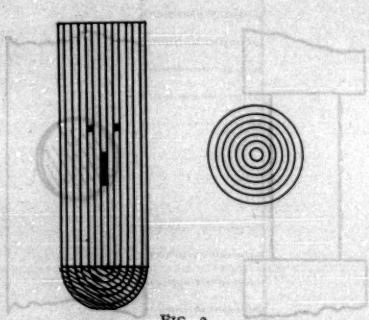

FIG. 2.

case met with in the bending of pillars. It may be proven that if we put a weight on a pillar it may not bend out in a bow, as we might suppose at first sight, but that the pillar divides itself up into segments, as shown in *Fig. 3*.

As I have said, there is an analogy; but it is difficult to see how it is to be applied to the case of a wire compressed uniformly all around. If we suppose, however, that, in the drawing, the die and wire have dissimilar cross-sections, it is not difficult to see, though I have not tried to work it out mathematically, how this may produce the result; for in that case every portion of the wire, as it passes through the die, would act as a short column, *Fig. 4*, and moreover, when the localized stress had once produced a non-homogen-

eous strain, the latter would tend to propagate itself even when the pressure was nearly uniform. Other examples of this effect are the cleavage of slaty rock, and the effects mentioned by Tyndall in his much (and I believe unjustly) abused book on diamagnetism. It will be remembered that by simply pressing some paramagnetic substances, they become diamagnetic, and he connected the effect with much reason with the presence of cleavage planes.

I have noted a phenomenon which would seem to show that the same nodal piling up of stress takes place when a bar is pulled apart. Going one day into the testing laboratory of Messrs. Hunt & Clapp, I noticed the assistants

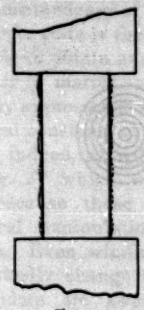

FIG. 3.

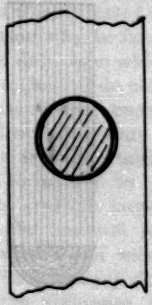

FIG. 4.

pulling some flat bars of aluminum. I placed myself so that the light from a window should be reflected to me from the surface of the bar which was being tested, expecting to see evidence of a hollow at the point where the bar would finally break. Instead, what appeared was this: two small hollows appeared, one near each fastening clamp. As the strain on the piece slowly increased, two more hollows formed. They crept together like ripples on water (each individual hollow remaining in its original position, but the new ones forming continually), until the two sets finally met in the middle, and, at the instant of meeting, the bar parted (*Fig. 5*).

It might appear possible to get rid of this æolotropic state by annealing. To a certain extent this is true, but other difficulties are introduced. It is impossible, by the means ordinarily used, to anneal a specimen without introducing impurities. Gases from the flame or from the air, or carbon from the coal, may be absorbed.

Now, when we speak of a substance as chemically pure, we are accustomed to consider it as pure enough for any physi-

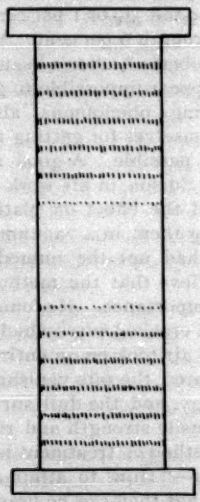

FIG. 5.

cal test. Yet this is not so; for quantities of substances absolutely inappreciable in chemical work affect the physical properties very greatly. Even Stas's silver would be unfit for physical tests, though in a perfectly annealed form; for, as Chatelier has shewn, the occlusion of a quite imperceptible weight of hydrogen changes the melting point of silver 39° C., and also changes the electrical conductivity and temperature coëfficient markedly. (Other

observers say that it is the oxygen-occluding silver which gives the false melting point. In either case the fact to which attention is called, *i. e.*, that small quantities of gas affect the melting point, is correct.)

Roberts-Austen's experiments on the tensile strength of gold alloys give a similar result. He shewed that $\frac{2}{100}$ of 1 per cent. of bismuth reduced the tensile strength of gold to one-twentieth of the value for the pure metal, and its elongation from 40 per cent. to zero.

At the same ratio the $\frac{1}{100}$ of 1 per cent. of bismuth would affect the tensile strength 6 per cent. Many other examples may be found in Roberts-Austen's beautiful researches.

Now, it might appear impossible to get rid of all of these discrepancy-producing phenomena, although means will readily suggest themselves for getting rid of some of them. Yet I believe it is possible. A good many years ago (in 1879, I believe), Mr. Edison, in his work on the incandescent lamp, had examined the effect on platinum and iron wire produced by heating them, in a vacuum, to a high temperature. His results had not the immediate practical value hoped for, but I believe that the method will prove of the greatest scientific importance. He found that, by this treatment, the pitted and cracked wires which had been produced by annealing in the air took on an entirely different nature. The cracks disappeared, the pits vanished, the soft, lead-like wires became springy, and the dull surface turned to a lustrous one. Both tensile strength and rigidity were greatly increased. This method of treatment is, I believe, the solution of the problem—"How to attain a standard physical state in metals, so that they can be used in physical work." If we take a wire, full of cracks and non-homogeneous through hard drawing, with occluded gases, and mixed with oxide, nitride and hydride (if this be possible), then, on heating it sufficiently in a high vacuum, as we do the filament of an incandescent lamp, we may drive off the occluded gases, decompose the nitride and hydride and compact the metal. By heating again in excess of hydrogen, and keeping the metal near the melting point we can reduce the oxide, and then further pumping will remove the hydrogen.

If the wire be pure to begin with, with the exception of admixture with gases, specimens can always be produced in a similar state and may be expected to give the same results as any other wire of equal purity and treated in the same way. In some experiments I have made, very concordant results were obtained.

It is evident that we require a "standard physical state," to which all materials should be reduced before being tested. If some chemical firm, or some scientific body, could furnish elements in a high degree of purity and in such a standard state, the theory of molecular actions would, in a few years, reach a state which cannot, with the present indiscriminate way of working, be reached in a century, if ever; for then, if one scientific worker, like Dewar, should make experiments on the electric conductivities of metals or their thermo-electric properties at different temperatures, and some other experimenter should work on the tensile strengths of the same substances, the results could be compared, and any possible connection between them could be detected. At present it is idle to compare such results since the materials differ so much.

I would, therefore, propose that *the "standard physical state" of metals be defined as that state which is produced by heating the metals in a vacuum for one hour at a temperature as close to the melting point as possible, and that all physical tests, so far as possible, be made with material which has been treated in this manner.*

In making tests for tensile strengths we come upon another source of discrepancy. This is due to the fact that when we test a metal we have a different material at the end of the test from that with which we started. By the very act of pulling apart, the material has become hardened. Theoretically, a perfectly homogeneous material should have no elongation and very little tensile strength, no matter how strongly its particles are held together by cohesion when test pieces are taken having cross-sections which are not very small, say, not less than the $\frac{1}{100}$ of a square inch; for if the metal remained homogeneous while being pulled apart, then any small inequality in applying a stress would

start a crack, and at the edge of this crack the stress would be piled up, and so the crack would continue and increase until, at length, the metal broke with but a small fraction of the weight it would support if the stretching hardened it. Therefore, for testing we must have standard sizes.[5] It is for this reason, probably, that the tensile strength of diamond, which, as we shall see is held together with a much greater force than the best steel, does not appear on actual test to be so great. But it is evident that if we could in any way make the stress perfectly uniform we should find that the diamond was much the stronger of the two.

In the case of diamond we cannot do this, but in the case of quartz we can; for if we draw the quartz out into a long, thin thread, by the method devised by Boys, then the strain will be applied very evenly at any point located a few hundred diameters from the ends. Therefore, though the tensile strength of quartz in large crystals is very small, in fine threads it has a tensile strength not much inferior, I believe, to a fair quality of steel when test specimens of the latter are taken having fairly large cross-sections.

Thus, there are good reasons for believing that if materials be arranged in two lists, one containing the materials in their order of hardness, and the other the same materials arranged in the order of their tensile strengths, the order in both lists will be found identical.

A most interesting question is this: "What is the nature of the force which holds the atoms of a metal together, and why is one metal stronger than another?" In other words: "What is the cause of cohesion?"

The theory which I now present to you was first published by me in August, 1891.[6]

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[5] The millimeter diameter wire has been used in much important work, and is desirable for many reasons.

[6] *Electrical World; idem*, August 22, 1891; *Science*, July 22, 1892, and *idem*, March 3, 1893. It is only fair to say that the substance of the first three papers and the greater part of the fourth was completed in a more extended form in 1890, but I was unable to find a publisher. From the letters notifying me of the rejection of the manuscript, I learned that the chief objection was the presence of the double charge on the atom, which was considered impossible on conducting atoms. It has since been shown

Briefly, it is this, that the force of cohesion is due simply to the ionic charges of electricity on the atoms.

For suppose that we consider a wire, taking a cross-section through it; then we have two layers of atoms, one on each side of the cross-section plane, and if we know the charge on an atom, we can calculate approximately the resultant attraction. This, in the following manner:[7]

From Rayleigh's experiments on the electrolytic equivalent of silver, we find that the atoms of a cubic centimeter of silver have a total ionic charge of about 1,000 coulombs. As the diameter of the silver atom is about 10^{-8} centimeters, there are 10^{24} atoms in a cubic centimeter. Therefore, the total quantity on a single atom is about 10^{-20} coulombs. On a single layer 1 square centimeter in area, the quantity will be 10^{-4} coulombs.

Considering, then, the two adjacent layers as two plates of a condenser 10^{-8} centimeters apart, and charged with 10^{-4} coulombs of electricity (supposing for convenience that the charges act as if concentrated at the centers of the atoms), we get for the force required to separate the two layers, 44×10^5 dynes.

Now, according to Wertheim, the actual value for the tensile strength of silver reduced to a cross-section of 1 square centimeter is 37×10^5 dynes, which, it will be seen, is quite as close an agreement as could be expected, considering the uncertainty as to the exact size of the atom.

How would the tensile strength depend upon the size of the atoms on this theory?

Consider my table of the elements here presented, *Fig. 6*,

(Burton, *Phil. Mag.*, **38**) that the atoms must necessarily be non-conducting. Moreover, though I was unaware of it at the time, the double-charged atom had previously been used by Helmholtz for his chemical theory. The writer was, however, the first to extend the province of the electrically-charged atom from its purely chemical functions to the phenomenon of cohesion and its allied physical effects. Since then other workers have entered the same field, *i. e.*, Chattock, who has given us a very satisfactory theory of dielectrics; Kelvin, who has given us the piezo-electric theory of quartz which bears his name; and Richartz, who has worked on the subject of magnetism.

[7] This calculation (of the atomic charge) was first made by Stoney, Brit. Assoc., August, 1874. See also Lodge, Brit. Assoc., 1885.

which I have found very convenient, more especially so as the discovery of the new elements has not necessitated any change in its construction. On one side of the prism round which the table is wrapped, we see all the metals which are used in the mechanical arts. These are the only metals about which we have data. The table, *Fig.* 7, shows

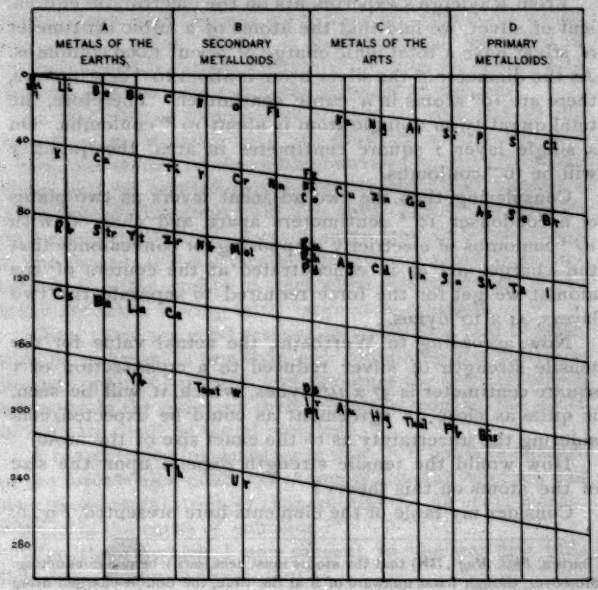

FIG. 6.

their atomic volumes. It will be noticed at once that those metals having the smallest atoms are the strongest. This is better shown in the following table, *Fig.* 8.

Suppose now we take two wires made up of atoms, but the atoms in one wire twice the diameter of those in the other. Consider the charges as before, concentrated at the

centers of the atoms. Since the charge on each atom is the same, and the smaller atoms are twice as close together as the large, twice as much work will be done in shearing the rod made of small atoms through a certain angle as with

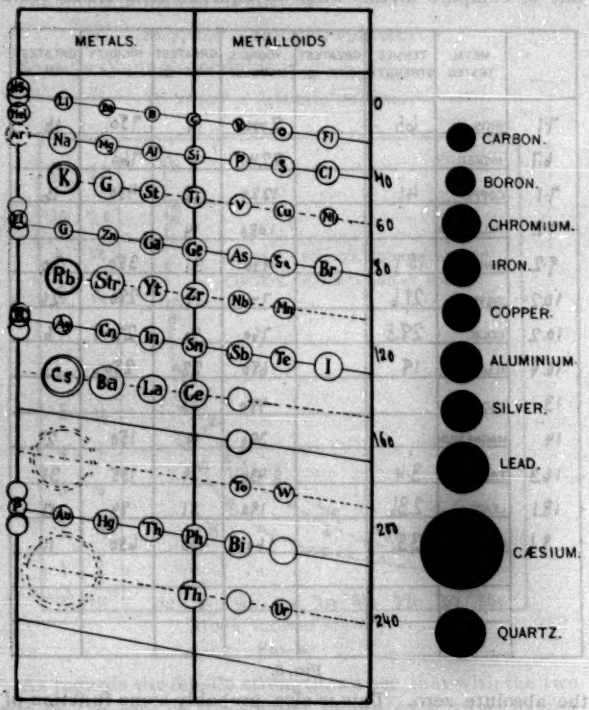

FIG. 7.

the rod of the large atoms. Moreover, in the smaller rod there will be twice as many atoms to be sheared; therefore, the force required to produce a given shear, *i. e.*, the rigidity, will vary as the inverse fourth power of the atomic diameter,

or as the $\frac{4}{3}$ power of the atomic volume.[8] The same will hold for Young's modulus.

We have not taken into account the fact that the rigidity and Young's modulus vary with temperature, so that it is only fair to compare metals when at equivalent distances from

	METAL TESTED.	TENSILE STRENGTH	GREATEST DIFF. %	YOUNG'S MODULUS.	GREATEST DIFF. %	RIGIDITY $\div 10^4$	GREATEST DIFF. %
7.1	IRON.	65		2000	14	750	16
6.7	NICKEL.			2240	6	760	
7.1	COPPER.	41		1220	22	490	16
9.2	PALLADIUM.			1050	14		
9.2	ZINC.	15.7		930	31	350	20
10.2	SILVER.	29.6		740	17	280	24
10.2	GOLD.	28.5		760	40	270	6
10.4	ALUMINUM.	19		680	23	250	3
13.	CADMIUM.			450	23		
14.	MAGNESIUM.			390	19	150	27
16.3	TIN.	3.4		490	34	195	35
18.1	LEAD.	2.36		190	51	94	17
9.1	PLATINUM.	35		1600	33	650	11

FIG. 8.

the absolute zero. This is also probably some function of the atomic volume, and I have found that atomic volume $\frac{4}{3}$ approximately agrees with facts. Consequently, the rigidity

[8] The law is, of course, only approximate. The fact that the atoms have so small a space in which to move is our warrant for treating them as if they were stationary.

and Young's modulus may be approximately expressed as varying inversely with the square of the atomic volumes.

The accompanying curve, *Fig. 9*, shows these relations. It will be seen that the agreement is fairly close.

The formula for the rigidity is

$$28 \times 10^{12} / (\text{atomic volume})^2.$$

That for Young's modulus is

$$78 \times 10^{12} / (\text{atomic volume})^2.$$

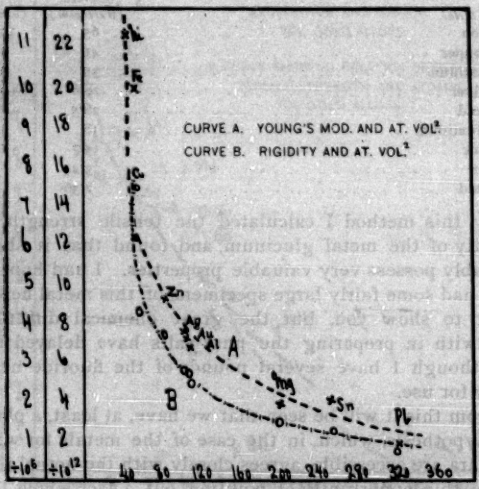

FIG. 9.

As regards the tensile strength, we see that with the two rods, in the case of the smaller atoms, each atom having the same charge, since the force varies inversely as the square of the distance, the attraction per atom will be 2^2 as great. Moreover, there will be 2^2 as many atoms. Hence, as in the case of the rigidity and Young's modulus, the tenacity will vary as the $\frac{4}{3}$ power of the atomic volume.

I find, however, that it is necessary to take into account, as before, the change with temperature. Assuming this to be proportional to the melting point in degrees measured from absolute zero, we get the following formula, which it will be seen agrees fairly well with experiment.

FOR WIRES 1 MILLIMETER IN DIAMETER.

Tensile strength in kilograms =

Absolute temperature of melting point ÷ (1·92 × atomic volume$^{4/3}$).

Metal.	*Observed. (Wertheim.)*	*Calculated.*
Iron	65	74
Copper	41	48
Platinum	35	48
Silver	29·6	29
Gold	28·5	29
Aluminum	18	18
Zinc	15·7	16
Tin	3·4	5
Lead	2·36	4

By this method I calculated the tensile strength and rigidity of the metal glucinum, and found that it should probably possess very valuable properties. I had hoped to have had some fairly large specimens of this metal here to-night to show you, but the great chemical difficulties met with in preparing the pure salts have delayed matters, though I have several pounds of the fluoride nearly ready for use.

From this it will be seen that we have, at least, a plausible hypothesis, which, in the case of the metals for which the data are accessible, agrees closely with the actual tests. I take this opportunity of pointing out a fact which I did not know till some years after the publication of this theory, and which seems to have been quite overlooked.[9] This is, that a relation between rigidity and atomic volume had been previously noticed by Wertheim, though his formula is radically different from that given by me, and he did not advance any theory as to its nature, or attempt to apply it to tensile strengths.

[9] *Annal. de Chim. Phys.*, III, **12**, 385.

The application of this theory to alloys is one of more difficulty. We see at once that, in general, the addition to a metal of large atomic volume of one whose atoms are small, must increase the tensile strength of the former. This was discovered some time ago by Roberts-Austen as an empirical fact. He proved it for the case of gold alloys. He shewed that the exceptions to the rule were caused by

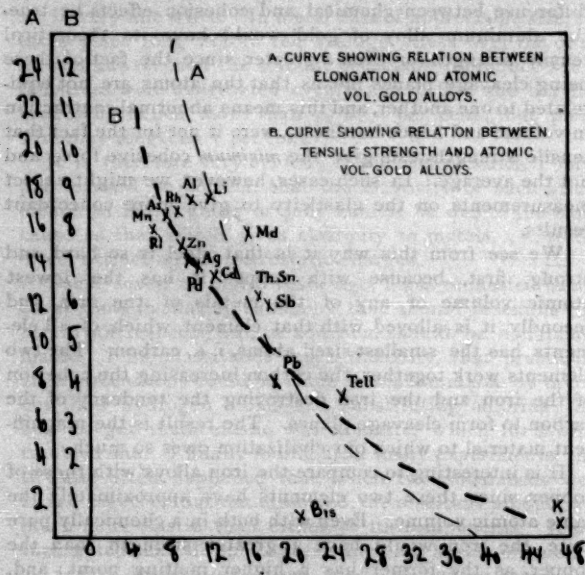

FIG. 10.

the fact that what we call chemical combination (*but which I believe to differ only in that the resultant product of a cohesion effect is isotropic, while that of chemical action has cleavage planes; or, in other words, that the atoms in the one case are symmetrically grouped in every direction, and in the other they are only symmetrically placed about certain axes or planes*) takes place; and he was able to prove that in the case

of one exception, that of the alloy of aluminum and gold, which gives a less (*Fig. 10*) tensile strength than it should theoretically, such an alloy is actually produced.[10] Even in the case of the chemical compounds, however, I believe that the rule still holds as regards hardness, though no experiments have been made, so far as I know, on these lines; for if what I have said as to the difference between chemical and cohesion effects be true, the aluminum alloy of gold would have its theoretical tensile strength (or even a greater, since the fact of there being cleavage planes means that the atoms are not equi-related to one another, and this means abnormal contraction in volume and hence hardness), were it not for the fact that tensile strength tests give the *minimum* cohesive force and not the average. In such cases, however, we might expect measurements on the elasticity to give more concordant results.

We see from this why it is that steel is so hard and strong, first, because with copper it has the lowest atomic volume of any of the metals of the arts, and secondly, it is alloyed with that element, which, of all elements has the smallest-sized atoms, *i. e.*, carbon. The two elements work together, the carbon increasing the cohesion of the iron, and the iron destroying the tendency of the carbon to form cleavage planes. The result is the magnificent material to which our civilization owes so much.

It is interesting to compare the iron alloys with those of copper, since these two elements have approximately the same atomic volume. Even with both in a chemically pure state, the iron would have a greater strength than the copper, as the former has a higher melting point; and, consequently, when both are at the same temperature, the atoms of the iron will be closer together. Moreover, we do not know of any substance, which has so small atoms as carbon, that will alloy with copper. It is possible that an alloy of *boron* with copper would result in a material of great

[10] A curve which does more justice to Roberts-Austen's researches is contained in his book on metallurgy. By an unfortunate accident I have to present *Fig. 10* instead.

value,[11] but I am not aware that this experiment has been made. Theoretically, it is promising. So, also, an alloy of boron with aluminum might be of value.

To speak next of elasticity: It is evident that the amount to which it is possible to stretch a metal before it breaks must be very small. Exactly how much can only be ascertained by measuring the strain necessary to produce set in very fine wires. In metal bars of appreciable size, set takes place long before the average stress over the cross section has reached the amount necessary to produce set if the stress were distributed evenly, and before the bar has been lengthened more than $\frac{1}{10}$ of 1 per cent.; but piano wire may lengthen 1 per cent.

It is therefore very evident, if the theory which I have put forward be correct, that the elasticity of such a substance as india-rubber or jelly cannot be due to the same cause as that which gives elasticity to metals, *i. e.*, to the direct attraction of electrostatic charges.

Some seven or eight years ago, I was requested to discover some insulating substance that should resemble rubber in all respects, but, in addition, should be non-inflammable. I found, without much difficulty, that practically all hydrocarbons could be made non-inflammable by taking out their hydrogen atoms and substituting chlorine; but how to get them elastic was a matter which for a while troubled me. I finally found, after many experiments, that it quite often happened that, when two substances were mixed together but not dissolved, the resultant product was much more elastic than either of its components. It was then noted that all substances which are highly elastic are, as actual observation shows, made of two or more compounds in a state of mixture. In the case of rubber, for instance, we have for its components, neglecting the oxidation product (which is not found in fresh rubber), two substances: one which is somewhat like horn—hard, elastic,

[11] M. Moissan has found, as I predicted some years ago, that the alloy of boron and iron is very hard. He has also succeeded in producing the well-known carbon boride in large quantities, and it would seem as if both these substances should have important applications.

but possessing very little extensibility; and another substance, like a very thick molasses, or a soft asphalt, or stearin pitch. Neither of the two has anything like the elasticity of india-rubber itself. The same holds good of other substances, as ivory, or soap-jelly.

How this mixing can confer such great elasticity is seen from the following considerations: Suppose we have a copper ball filled with a practically incompressible fluid, such

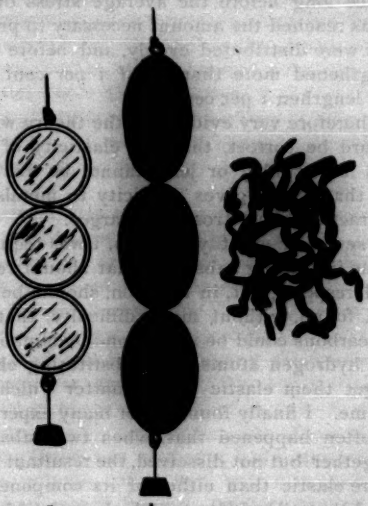

FIG. 11.

as water, *Fig. 11 a*. Let the radius of the sphere be 1 centimeter. Suppose I pull it out until it forms an ellipsoid, and until its major axis is 3 centimeters long, *Fig. 11 b*. Then, on the assumption that the thickness of the skin remains constant, we have an increase of area of 13 per cent., or a linear elongation of 6 per cent. But as the skin is stretched, it contracts in thickness, so that, for this reason, a less linear extension is needed, in this case only about 1·5 per cent.

Thus we get an elongation of 50 per cent., at the expense of only 1·5 per cent. of elongation of the material which does the stretching.

Now, it is fairly easy to see that a lump of the tar-like component of india-rubber, surrounded by strings of the horn-like substance, would give a similar effect; for the strings may be considered as forming the walls of the sphere, and the viscous substance as taking the place of the water, *Fig. 11 c*. Thus we may have a very great extension of an india-rubber strip, with but little actual extension of the horny substance, and none at all of the other component.

That this is the true explanation of the large elasticity in such substances is rendered probable from other considerations. The first is the fact that if we masticate the rubber too long, or treat it in any way which would destroy such a constitution as I have described, it loses its elasticity in great measure. Another convincing proof is the following: What will happen if I suddenly pull out the water-filled ball? I compress the water, and it will heat. If I leave it extended for some time, and then let it contract, it will cool. Exactly the same phenomena can be observed in the case of india-rubber by placing a rubber band between the lips and pulling it.

Again, what would happen if, whilst the ball were stretched, I heated it? Evidently the water would expand, and, in expanding, would force the ball to return to its original spherical shape. Here we have a curious paradox —contraction caused by expansion—and this phenomenon is exactly duplicated in the case of rubber.

Evidently the expansion will be asymptotic in the case of the ball. Here is a curve, *Fig. 12*, showing that the same holds for the rubber strip. The area between the up and down curves is due to hysteresis, and, as you will see, strikingly resembles the hysteresis curve of iron, as also do many curves of chemical action.

The hysteresis is caused by the fact that, whilst the strip is being stretched, it gives out heat, and, whilst contracting, absorbs it again. (In passing, I may say that this hollow, water-filled ball would seem to be capable of some practical

applications. As one, I would say that if a weight be hung to the bottom of such a ball, it would form a very sensitive thermal indicator, since it would give a much greater movement than either the water or copper would if they expanded separately. A series of balls could be used, instead of a spring, where great elasticity and little fatigue were desired, or for buffers, and would have a great advantage over rubber in that the water has a much greater capacity for heat than india-rubber.)

My reason for taking up this branch of the subject is that, having discussed metals and alloys in the isotropic

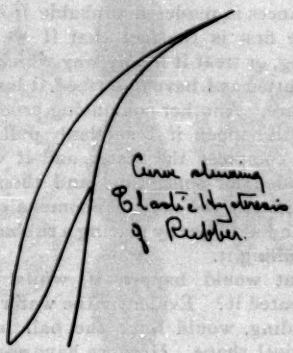

FIG. 12.

state, and in an æolotropic state produced by pressure or chemical action, the subject of metals and alloys rendered non-homogeneous by rolling, forging or other manipulations would naturally follow. We are all familiar with the fibrous structure shown by rolled and forged soft iron, and here we have, just as above, a structured substance which is thus rendered more elastic.[12] Though this is not accomplished to nearly so great a degree, I believe that the principle is the same, and having discussed it so far in the case of or-

[12] See, for instance, the cuts given by Seaton, in *The Engineer*, April 10, 1868.

ganic substances, it is unnecessary for me to say more, except this, that the mysterious failures of wrought iron may be analogous to this loss of elasticity of rubber which has long been kept under tension, as we see it in the case of rubber bands long used in holding letters. In both cases, possibly, the weakening is due to the fact that the greater part of the longitudinal strain comes on the fibrous constituent. To take a typical case, as it was reported to me, the bed-plate of a large engine was fastened down with the best wrought iron bolts screwed up tightly. After the lapse of about ten years, the bolts were removed and found so brittle that they broke when dropped on the floor. This certainly seems analogous to the case of the rubber band. Possibly the vibration may have helped matters. It would be an interesting experiment for some of our engineering laboratories to undertake, to suspend some pieces of iron stretched by weight, to, say, one-quarter of their set stress, and to test them after the lapse of a few years, during which time some of them had been constantly subjected to vibration.

The last phenomenon which I shall discuss in this lecture is elastic hysteresis, by which is meant the failure of a strained metal to return exactly to its original position.

This is most noticeable when wires are used as suspensions for mirrors, or needles in delicate apparatus. In a D'Arsonval galvonometer, for instance, if we make the suspensions of copper wire, on deflecting it and then removing the force, the coil will not return exactly to zero. This is due partly to the fact that the copper in the coil has become magnetized (as was first pointed out, I believe, by Mr. Willyoung), and partly because the wire has received a permanent set, though the twist was far within the elastic limit. We see very easily how this can happen. In the copper wire, no matter how carefully we anneal it, some of the atoms will be in positions of unstable equilibrium, for the atoms are all vibrating with great velocity, and, though these atoms have a certain *average* velocity, and as such exercise a certain average kinetic repulsion for each other, and though this repulsion does not get to be sufficient to overcome the attraction of cohesion until the body is heated

to that temperature at which it becomes a gas, yet, as this velocity is only an average, a very considerable number of the atoms have velocities differing from this mean amount.

The number and the amount of difference will be a question of probabilities; but we know so little about solids that it is impossible to calculate the result. Still, we may be fairly sure that there is always a certain number of atoms in the wire whose velocities are so high that their kinetic repulsion nearly or quite overcomes the attraction of cohesion.[13] If the wire be not strained by twisting, these atoms will not affect matters, but if the wire be twisted, then the atoms are all in a strained position, and when any atom can overcome the force of cohesion, it will move into an easier position. Consequently, when the twisting force is removed, the wire will now turn back and would come to its original position, but for the fact that these atoms, which had moved into positions where they were not strained when the wire was bent, now become strained when the wire untwists and tend to hold it back.

To this effect, when produced by longitudinal stress, may possibly be due that brittleness in wrought iron above referred to.

Another action, first pointed out by Kohlrausch, is that the wire appears to have a sort of memory. Thus, if we twist a wire clockwise, and then counter-clockwise, then clockwise again, on letting it go it first returns nearly to zero, then twists counter-clockwise, clockwise and counter-clockwise again in succession. This will readily be understood from what has been said above, if we note that the rate of creeping after the return to the false zero decreases as the wire comes nearer to the true zero. It is really the superposition of three curves.

Hysteresis is also of interest from this point of view, inasmuch as it gives us an idea how consciousness and thought may be produced by merely physical phenomena. In fact, when we consider the great complexity of the or-

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[13] *Vide*, for instance, the recent experiments of Roberts-Austen on the diffusion of metals at comparatively low temperatures.

ganic molecules which form part of our bodies, it is even possible that this is the real cause. However, it is unnecessary to speculate so far in advance of our knowledge of the subject.

But as every one is more or less interested in the study of mental phenomena, I will explain what I mean by saying that hysteresis enables us to see how purely physical causes might give rise to all the phenomena which we attribute to a something which we call mind.

I hesitated some time before I decided to present the matter in this aspect before you, because I know how severely it can be criticised. Still, the theory is now some two years old, and I have been unable to see any flaw in it. I have presented it to a number of men skilled in the science of mental phenomena, and found no objections to it which I can regard as valid. Therefore, I lay it before you, in the hope that, even if the theory as I present it be not true, it may at least lead, from the newness of the view, to results of value.

Objections may be raised. It may be said that a physicist dealing with mental phenomena is going somewhat beyond his province. I should be somewhat sensitive to such a criticism. I remember, whilst a schoolboy, reading a speech of some Greek orator, in which he hits at his rival by commenting on the jaunty way in which the latter used to preface his addresses—"O, fellow-citizens, I haven't given the matter any particular consideration; in fact, I didn't know anything about it till a few moments ago; but if you want to know exactly what to do I will tell you." I suppose I would have been caned for such a translation as that, but I have given the meaning about as I remember it; and I thought at the time it was a pretty nasty hit. Therefore, I will say that I spent—wasted, I am sometimes inclined to put it—a considerable portion of nine years in the study of metaphysical writers; consequently, what I say I do not say as one who is entirely ignorant of the subject, though I may be a little rusty in some of the jargon, which, in metaphysics, as in other pseudo-sciences, makes an important part of the subject.

Again, it may be objected that the theory is incomplete and insufficient. That I should be able, alone and in the space of a few years, to develop a complete and satisfactory theory of mental phenomena, is an idea which has not occurred to me.

I find that practically all my scientific friends with whom I have exchanged opinions agree that thought will ultimately be found to be a purely physical action. I find that the non-scientific thinker is always repelled by this idea, and speaks of the wickedness of attempting to degrade mind to the level of matter; but, in the first place, it would appear rather as the raising of matter to the level of mind; and, in the second place, we have to go on the evidence that is placed before us.

But to appreciate the general trend of evidence and to get a definite idea of how life can be a branch of physics are two different things. Many things which are observed in crystal formation are somewhat akin to the vital processes, and it has recently been shown that movements are produced by capillarity in certain mixtures of oil and water, which strikingly resemble protoplasmic motions. Yet the subject is an unusually complicated one. It took several thousand years to make quinine, but the atoms in a molecule of quinine are only a small fraction of the number in a molecule of protoplasm; and with the increasing number comes increasing unstableness, so that we need not hope to see living matter artificially produced, for, I believe, at least a hundred years, even taking into account the fact that scientific knowledge increases at a compound rate—though of course we may at any moment learn that some fortunate experimenter has, by a series of lucky chances, hit upon the solution.

Can we conceive of the thing? Some time ago, as the result of my metaphysical study, I should have said "no," since the result (about the only one) of this pseudo-science is to give one a strong mental set towards regarding mind and matter as things eternally distinct. This I now perceive to rest on the same kind of foundation as Zeno's paradox about motion.

I shall touch very briefly on the matter, though it is a most interesting one; and, during the two years I have been working at it, it seems capable of very considerable development.

Suppose that we took two manikins, and by ordinary mechanical contrivances, say with the aid of a device worked by the expansion of a heated fluid, constructed one of them so that, on bringing it up to a lighted candle, it would thrust its hand into the flame, and when the hand became heated the manikin would withdraw it, the action depending upon the elasticity of a wire spring which we may suppose to be placed in its head. So far, the toy is simply an automaton. It is influenced entirely by circumstances. Bring it to the candle a thousand times, and it will still thrust its hand in the flame.

Suppose we now unscrew the head and screw on another one in which the spring is made of a metal showing elastic hysteresis very markedly. Now, on bringing it to the candle, it will put its hand in the flame as it did before and will bring it out again; but now there is a difference. The wire has its atoms arranged differently, and so the future action of that spring will no longer be dependent merely upon its circumstances. Another factor enters in, that is, the past history of the spring; and the action of the manikin will now be due to the resultant of the two. So that by taking advantage mechanically of the hysteresis of the spring, we may, though using the same mechanism in the body part of the manikin, have two entirely separate sets of acts. So with our device. Suppose the second head is screwed on; bringing it up to the candle as mentioned before, the hand is thrust in and withdrawn. Bring it up a second time; instead of the act being repeated, the hand is now withdrawn, and no matter how many times the flame is placed near it, the hand always withdraws. If, however, the head be left alone for a few months; then, on bringing the candle near, the hand will be thrust in it again; the manikin has temporarily lost its memory, but, the impression being again renewed, it now once more avoids the flame.

Suppose, now, we have a more complex manikin, in fact, a manikin capable of acting as a man does, and arranged so that any two movements of parts of its mechanism, which took place consecutively, were thereafter always linked together, just as two consecutive twists in a hysteretic wire; then the fact that all actions would be divided into two parts, one affecting it directly and the other not, would give rise to actions which would not be differentiated from those caused by what we call consciousness. In other words, it is possible to conceive consciousness as being an acquired thing, and a necessary consequence of one's actions being determined, as in the case of the manikin, not alone by one's circumstances, but also by one's previous history.

We have gone far enough into this question for a lecture on physics; but I cannot refrain from pointing out that this offers the only rational means of escape, of which I am aware, from the old dilemma: "How can a man whose actions are determined by circumstances, heredity, etc., be held responsible for his actions?" The answer, on this theory, is very simple: "Man is himself the majority of his circumstances," and as his circumstances are responsible for his actions, he, as the majority of circumstances, must be held chiefly responsible.

I must reiterate that this is to be taken as an illustration merely of the way in which mental phenomena *may* be due to physical causes. Ability to distinguish between partial and complete parallelism is all that separates the so-called "crank" from the scientific reasoner. When we see two lines of fact lying side by side we are too apt to consider that we have happened upon a tramway to truth, and too instant to equip it with a theoretical rolling stock. If the parallel be not exact—if the rails spread—there is grief for the investigator. Hence always the very greatest need for caution.

A REVIEW OF RECENT SYNTHETIC WORK IN THE CLASS OF CARBOHYDRATES.*

By Helen Abbott Michael.

Evolution is so universal, whether as exhibited in the unfolding of human conceptions, or in the making of worlds, that in all reason it may be accepted as a cosmic principle. The factors of evolution are essentially constructive and destructive ones, since growth and decay, progress and retardation, synthesis and decomposition, accompany the rhythmic pulsations of this general condition of change. Likewise, the chain of chemical causality may be conceived of as closely correlated with this presentation of evolution. The notion advanced in this consideration precludes the thought of permanence. In chemical activity the atoms are ever shifting their position in space, and this unrest is indicative of the fundamental law of advance. Howsoever stable and fixed may seem the individual links of this chain, in reality the seeming stability is a condition of variation and re-arrangement of the atoms and molecules. The molecule, that smallest portion of matter self-existing when considered as the resultant of chemical reaction, is but a state of force equilibrium between the becoming and the vanishing.

In this evening's review of recent synthetic work, in the sugar group, these constructive and destructive processes are well exemplified; also, the unfolding changes so apparent in other manifestations of universal phenomena are likewise observable in the realm of chemistry. This underlying unity and dominant principle unites all aspects of the cosmos and connects the parts into a living universe of the whole.

Evolution, when applied to chemistry, as elsewhere, com-

* A lecture delivered before the Franklin Institute, March 8, 1895.

prises the notion that the conceptions of the science advance with the unfolding of its parts.

The evolution of chemical compounds is theoretically illustrated by the building of more complex compounds from simple compounds, themselves formed from the elements, which, no doubt, in turn come from still simpler sources. The complex bodies of the same type, as, for instance, the hydrocarbons of the fatty series, show development on their own lines. Passing from the fatty hydrocarbons to those of the aromatic series is another example and indication of progress to syntheses beyond. In the laboratory these processes no doubt oftentimes are carried out by circuitous methods, as Nature's sequences in these particulars are unknown. In the natural changes that rocks, plants and animals undergo, a self-directive chemical consciousness, adequate to the needs of the respective conditions, doubtlessly obtains.

There was a time, not so long ago, when many of the chemical compounds resulting from the chain of existence were isolated from animal and plant life. The key of chemical change was looked for in the study of plants, and to these sources, from life, chemists turned for new research fields.

A little later, chemical synthesis, or the production of compounds by artificial means, had its beginning. From time to time, at longer or shorter intervals, appeared the announcement of the synthesis of some compound hitherto derived from plant or animal life. But the later years of this century, from the chemical point of view, may be regarded specially as synthetic years, ever nearing the zenith of greater attainment.

The subject of sugars early attracted the attention of chemists, not only because of the industrial aspects, but also, being one of the main divisions of the classification of compounds, the study of its varieties and composition has been untiringly pursued. The vision arose in the long past of its possible synthesis. Liebig first conceived the idea of making sugar artificially. But the synthesis of this important group of compounds defied all efforts until compara-

tively recent times. The first mixture of synthetical sugars was obtained by Butlerow,[1] by the action of lime water on oxymethylene, in the form of a syrupy liquid which he named methylenitan. In 1863, Van Deen, by the oxidation of glycerine, discovered a compound which reduced salts of copper in alkaline solution, and showed other properties indicative of a sugar, although of a simpler kind than those found in nature. The discoveries of Loew, Tollens and Fischer have brought the investigations of sugars to our own times.

The researches of Naegeli, from a botanical standpoint, led him to advance a theory that starch was the origin of sugar in plants.

A later purely chemical hypothesis of the synthesis of sugars from simple compounds in the living cell, which, in turn, yield more complicated compounds, is thought by many to be a more satisfactory theory, for it coincides with our ideas derived from other branches of scientific investigation in support of the notion that from simple integrals arise intricate structures. But it is quite probable that both processes of construction and destruction are carried on simultaneously in the plant. In the laboratory, it is possible, starting with the elements carbon, hydrogen, and oxygen, to form, from these elements, compounds which are found in vegetable life. From the simple bodies thus derived are the means ready at hand to proceed to compounds of a sugar type.

The carbon dioxide in the plant is derived from the external environment of the air and soil, or the gas is generated within the plant cells. Under the influence of sunlight, carbon dioxide and water yield formaldehyde, a compound containing the group (CHO); *i. e.*, one atom respectively of carbon, hydrogen, and oxygen, known as the aldehyde group, united to hydrogen by the residual affinity of carbon. According to Baeyer, formaldehyde is the source of the plant's sugar.

In the chlorophyll grains of the green part of the leaf, it is supposed that the formation of glucose takes place.

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[1] *Ann.*, **120**, 295.

The aldehyde group enters into the constitution, and is characteristic of many of the sugars. One of the divisions in the classification of sugars containing this group is known as the aldehyde sugars. As a comprehensive name for the class, the word *aldose* has been adopted. The other class of sugars is known as the *ketose* sugars, so called from the ketone group (CO), or carbonyl, contained in their molecules.

The ease with which formaldehyde polymerizes, under favorable conditions, qualifies this compound eminently for its function in sugar formation.

Polymerization is the amalgamating, so to speak, of two or more aldehyde groups, forming a carbon compound containing a greater number of carbon atoms.

In considering the polymers of formaldehyde, Baeyer suggested that, under the influence of the contents of the plant cells, 6 molecules of formaldehyde polymerize to form 1 molecule of glucose, $6HCHO = C_6H_{12}O_6$.

It has been claimed that formaldehyde occurs in plants, and has been found in very small quantities in plant cells; but in any great proportion it acts as a poison to the living plant, and Fischer has suggested, in consequence, that there can be no doubt that other intermediary compounds occur in the formation of sugars. Bokorny[1] has made an interesting observation on the assimilation by the green cells of algæ of a double compound of formaldehyde and sodium bisulphite. He has shown that, if plants are deprived of starch and placed in an atmosphere free from carbonic acid, they are capable of forming considerable quantities of starch under the influence of sunlight, if fed upon this compound. In the dark the conversion of formaldehyde into starch does not take place.

Loew, by treating formaldehyde with lime, obtained a sugar which he called formose. Fischer has shown that this product contains sugar compounds of the composition $C_6H_{12}O_6$, and among these, one named acrose, which stands in very close relation to natural glucose.

It may be well to state here that the term sugar includes a variety of substances. It includes fruit sugar, glucose and

[1] *Landw. Jahrbuch.* **21**, 445.

chemically allied sugar groups, some of which contain more and some less carbon atoms than glucose. These compounds are not to be confounded with the food material derived from the sugar cane or beet root, and milk sugar. Starches and gums, though conveying little idea of sugar, are chemically to be considered as sugars.

The characteristics of these different compounds are very unlike. They vary from very soluble to insoluble compounds, and from crystalline to non-crystalline bodies. But the insoluble compounds, like starch and cellulose, may be converted into the soluble sugars by the action of heat and dilute acids, and by certain ferments, as diastase. The reaction which accompanies this conversion involves the taking up of water, and at the same time the complicated molecule splits into several simpler ones. This reaction is called hydrolosis:

$$x(C_6H_{10}O_5) + xH_2O = xC_6H_{12}O_6.$$

As will be observed, the sugar group—collectively designated as "carbohydrates"—comprehends a vast widening-out vista of compounds, from a simple compound derived directly from the elements, to complex bodies with numerous isomers.

The sugars of physiological consequence are widely spread in animals and plants, and, as carbohydrates, constitute one of the three great classes of natural organic compounds, the fats and albuminoids constituting the other two classes. Lavoisier discovered that the materials of which carbohydrates are composed were carbon, hydrogen and oxygen; but the objection to the use of the term carbohydrate, which is defined as a compound containing carbon and hydrogen and oxygen in the proportion of 2–1, is its non-universality. The sugar called rhamnose, $C_6H_{12}O_5$, may be mentioned as an exception to the definition, but for purposes of classification the name carbohydrate has been retained by writers.

The carbohydrates have been divided for convenience into three groups:

(1) Simple sugars, or monosaccharides, as grape or fruit sugars.

(2) Decomposable sugars, or polysaccharides, as cane or milk sugar and raffinose.

(3) Polysaccharides unlike sugar, as starch, cellulose and dextrine.

The polysaccharides are bodies made up from several simple sugar molecules, uniting with elimination of water. Thus, cane sugar may be converted into grape and fruit sugar by hydrolytic reaction, as shown by the equation:

$$C_{12}H_{22}O_{11} + H_2O = C_6H_{12}O_6 + C_6H_{12}O_6;$$

consequently, the simple sugars, like glucose, appear as the basis of the entire group.

In Nature, the simple sugars, or monosaccharides, are found not only as carbohydrates, but they occur also in combination with phenols as glucosides.

From the widely spread distribution of glucose, its uses as a food product, and considered chemically as the basis of more complicated carbohydrates, it deserves careful consideration.

The name hexose, which is the general name for the glucose group, as the word implies, shows that 6 carbon atoms enter into the composition of the individuals of the group. These carbon atoms are united in an open chain, each carbon atom, except one at one end of the chain, being united to a hydroxyl (OH) group. This end carbon atom is united with hydrogen and oxygen, forming an aldehyde group which is peculiar to these sugars. Glucose and sugars of its class are represented by the constitution which expresses an aldose or aldehyde sugar, $CH_2OH \cdot (CHOH)_n \cdot CHO$.

Fruit sugar, or ketose, is expressed by the formula:

$$CH_2OH \cdot (CHOH)_n \cdot CO \cdot CH_2OH.$$

The reason for accepting this atomic arrangement to express the constitution of the glucose and fructose groups is based upon several considerations. Grape and fruit sugar, on reduction with hydrogen, yield the alcohol mannite. Galactose, which is also an aldehyde sugar, under the same conditions gives the alcohol dulcite. The 6 hydrogen

atoms of the hydroxyl groups of these alcohols are replaced by acetyl groups on treating them with acetic anhydride, so they must be considered as the hexavalent alcohols of the above sugars.

The aldehyde character of glucose and galactose is also shown by their behavior towards oxidizing agents. On partial oxidation, by chlorine or bromine water, they yield respectively gluconic and galactonic acids. By complete oxidation they both give saccharic acid.[3]

Conversely to the aldehyde sugars, fruit sugar is slowly attacked by bromine water. By the action of a more powerful oxidizing reagent it is decomposed into products containing fewer carbon atoms.

The aldehyde and ketone character of these compounds is shown by the readiness with which the sugars form hydrazone and osazone compounds. This reaction with phenylhydrazine is characteristic of all compounds containing aldehyde and ketone groups.[4]

The sugar varieties which to-day go to make up a magnificent display of synthetic skill include many isomers, depending upon the different arrangement of the atoms in space. In order to have a clear view over this field, it is important to ascertain the spacial relations or configuration of each member of the sugar groups.[5]

The latest publications by Emil Fischer on the stereomers of the sugar groups show an admirable agreement between the conflicting facts pertaining to the sugars which have poured in from isolated researches during past years, when these are considered in the light of Le Bel and Van't Hoff's

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[3] When a solution of the alcohol mannite is heated for some hours to 42° C. with nitric acid, it is oxidized to mannose; if the reaction is continued with increased heat, the oxidation is carried on to the acid formation.

[4] $CH_2OH(CHOH)_4CHO + C_6H_5HN_2H_2 = CH_2OH(CHOH)_4CH(N_2HC_6H_5) + H_2O$

$CH_2OH(CHOH)_3CO.CH_2OH + C_6H_5HN_2H_2 = CH_2OH(CHOH)_3C(N_2HC_6H_5).CH_2OH + H_2O$

[5] The configuration of a compound is the relative position of its atoms in space. The portion of chemistry treating on this subject is called stereochemistry.

theory. The names of these investigators are especially identified with stereochemistry, although others have followed in the same lines.

Among the writings of the past, the geometrical forms of matter were suggested by the Greeks, and later by Swedenborg as a possibility; but it was Pasteur, in 1860, who gave the underlying idea of grouping of atoms in space.

This theory explains the existence of two or more compounds of like chemical composition, by assuming different dispositions of the atoms entering into the compound.

The simplest hydrocarbon, methane, is conceived as being a tetrahedron with a carbon atom in its centre and one hydrogen atom joined at each of its four angles. The carbon atom of this compound is symmetrical, inasmuch as all the atoms to which it is united are of a like kind. In such a case stereomers are impossible.

But in order to have the conditions for stereosomerism, it is necessary for a compound to contain one or more atoms of asymmetrical carbon; that is, a carbon atom united by all of its four bonds to atoms or groups of atoms of different kinds.

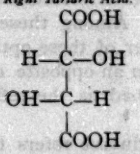
Methane may be represented, for illustration, by a pasteboard tetrahedron model,[6] the angles being painted red to distinguish the points of carbon's union with hydrogen atoms. If this model be placed angle to angle with a second methane tetrahedron, the hydrogen atoms will coincide, and if one of the models be superimposed upon the other, the hydrogen atoms at each of the angles will touch, showing the symmetrical grouping. The symmetry of the molecule is not disturbed when two or three different kinds of atoms replace the hydrogen atoms of methane. But when all of the hydrogen atoms are replaced by different kinds of atoms, it will be found, on bringing the angles of like color of two models together and superimposing the one model upon the second model, that the angles of like colors cannot be made to coincide.

[6] The subject here and what follows was explained by means of models and charts.

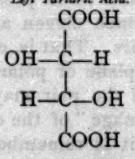
Lactic acid is an illustration of a compound containing an asymmetrical carbon. This compound, represented by the constitution, $CH_3 . CHOH . COOH$, contains two symmetrical carbon atoms, one at either end; the carbon atom which occupies the middle position is the asymmetrical carbon, since this atom is united by its four bonds with different atoms or groups. The presence of this middle carbon atom induces the conditions which cause lactic acid to appear under two *acid* modifications. By the action of these compounds on the rays of polarized light, which are turned to the right or left, depending upon the isomer, the acids are known as the right and left lactic acids. In uniting they give an inactive form.

In connection herewith, it may be well to mention the tartaric acid experiments of Pasteur. On working with certain of the salts of that form of tartaric acid, called racemic acid, he noticed that he could separate them into two crystalline forms, which in aqueous solution behaved differently towards polarized light. According to the direction that the solutions of the crystals turn the plane of polarized light, they are known as the salts of the right and left tartaric acids. The corresponding acids contain two symmetrical and two asymmetrical carbons. They may be represented in this manner:

Right Tartaric Acid.



Left Tartaric Acid.



The two active modifications may be brought together, and, when united, give the inactive form, or racemic acid.

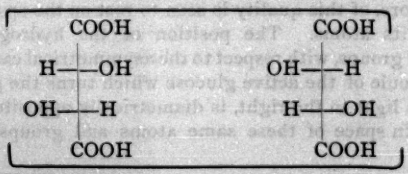


TABLE I.—Pentose, Pentonic Acid, Pentite and Trioxyglutaric Acids.

1	2	3	4	5	6	7	8
Mirror Images.							
COH HO—H HO—H H—OH CH_2OH	COH H—OH H—OH HO—H CH_2OH	COH H—OH HO—H H—OH CH_2OH	COH HO—H H—OH HO—H CH_2OH	COH H—OH HO—H HO—H CH_2OH	COH H—OH H—OH HO—H CH_2OH	COH HO—H H—OH H—OH CH_2OH	COH HO—H HO—H H—OH CH_2OH
l—Ribose. *l*—Ribonic acid.		*l*—Xylose. *l*—Xylonic acid.		*l*—Arabinose. *l*—Arabonic acid.		*d*—Arabinose.	

9	10	11	12
COOH H—OH H—OH H—OH COOH	COOH H—OH HO—H H—OH COOH	COOH H—OH HO—H HO—H COOH	COOH HO—H H—OH H—OH COOH
Ribo-trioxyglutaric acid. Adonite (inactive).	Xylo-trioxyglutaric acid. Xylite (inactive).	*l*—Trioxyglutaric acid. *l*—Arabite.	

Hexose, Hexonic Acids, Hexite and Saccharic Acids.—*a*. Mannite Group.

13	14	15	16	17	18	19	20
COH H—OH H—OH HO—H HO—H CH_2OH	COH HO—H HO—H H—OH H—OH CH_2OH	COH HO—H H—OH HO—H H—OH CH_2OH	COH H—OH HO—H H—OH HO—H CH_2OH	COH HO—H H—OH HO—H HO—H CH_2OH	COH H—OH H—OH HO—H H—OH CH_2OH	COH H—OH HO—H H—OH H—OH CH_2OH	COH HO—H HO—H H—OH HO—H CH_2OH
l—Mannose. *l*—Mannic acid.	*d*—Mannose. *d*—Mannic acid.	*l*—Idose. *l*—Idonic acid.	*d*—Idose. *d*—Idonic acid.	*l*—Glucose. *l*—Gluconic acid.	*l*—Gulose. *l*—Gulonic acid.	*d*—Glucose. *d*—Gluconic acid.	*d*—Gulose. *d*—Gulonic acid.

The configurations of the acids corresponding to the above have been omitted.

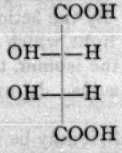
b. Dulcite Group.

27	28	29	30	31	32	33	34
COH HO—H H—OH H—OH HO—H CH_2OH	COH H—OH HO—H HO—H H—OH CH_2OH	COH HO—H HO—H HO—H HO—H CH_2OH	COH H—OH H—OH H—OH H—OH CH_2OH	COH H—OH H—OH H—OH HO—H CH_2OH	COH H—OH HO—H HO—H HO—H CH_2OH	COH HO—H H—OH H—OH H—OH CH_2OH	COH HO—H HO—H HO—H H—OH CH_2OH
l—Galactose. *l*—Galactonic acid.	*d*—Galactose. *d*—Galactonic acid.						*d*—Talose. *d*—Talonic acid.

The inactive acid may be separated into its active components by chemical means, or by the action of certain ferments. These ferments have the effect of destroying either the right or the left modification.

There is another inactive form of the acid, known as the anti-tartaric acid. This is the result of synthesis, and is not decomposable into active parts.

Anti-tartaric Acid.



From what has been said it will be easy to understand the parallelism of Pasteur's classical experiments with the sugars and the application of this theory to other classes of compounds.

With the simple sugar molecules the conditions are not so complex as in the higher sugar series, and the number of stereomers is less. With an increasing number of carbon atoms the conditions of asymmetry increase and stereomers are more numerous.

In the case of glucose the number of asymmetrical carbons is four. The possible number of stereomers is sixteen, of which eleven are known. Among these, five are optical pairs. That is, each member of these optical pairs turns the plane of polarized light in an opposite direction, and one of the pair may be described as the reflected or "mirror image" of the other.

When it is remembered that glucose refers to a compound which appears under two forms in respect of its action on polarized light, the explanation, from what has gone before, of this quality is seen to rest on the space position of its atoms. The position of the hydrogen and hydroxyl groups, with respect to the asymmetrical carbons in the molecule of the active glucose which turns the plane of polarized light to the right, is diametrically opposite to the position in space of these same atoms and groups in the

other modification of glucose which turns the plane of polarized light to the left.[7]

The right glucose may be spoken of as the "mirror image" of the left one, for by no possible turning can the configuration of the one be superimposed upon the other. Thus they are called enantiomorphic; but united, they give the modification inactive towards polarized light. The inactive glucose may be again decomposed into the two active forms.

The question naturally arises: Why are these configurations represented as they are on the diagram?[8] It would carry us beyond the time allotted for this occasion to go into the reasonings for each case. I will only take one or two examples. But it may be stated generally that the observations made on these sugars from experimental facts are in accord with theory.

On the chart, beginning at the top of the diagram, are the two *triose* sugars, each with one asymmetrical carbon. On the next lines are the four *tetroses*, which have been made synthetically. There are eight *pentose* sugars having three asymmetrical carbons; and below these are represented the sixteen *hexose* sugars, to which glucose belongs. I have not considered it necessary to continue the representation of the higher sugars on the chart.

But, suppose that I should change the aldehyde group of these sugars into a corresponding alcohol group, it would become apparent that the conditions for asymmetry were changed. Each of the end carbon atoms, in its atomic relations, is alike, and these alcohols contain only two asymmetrical carbons. The configurations for the pentose sugars, one and two, here given, are unlike. They are the mirror images of each other. When reduced, however, to their alcohols, the identity of the alcohols arising from these two sugars becomes apparent on turning the end group of one of the compounds in the plane of the diagram, and bringing this group to the top of the other configurations. Also, if these alcohols are imagined to be the acids of the group, the tri-oxyglutaric acids, the (COOH)

[7] This was represented on a diagram.

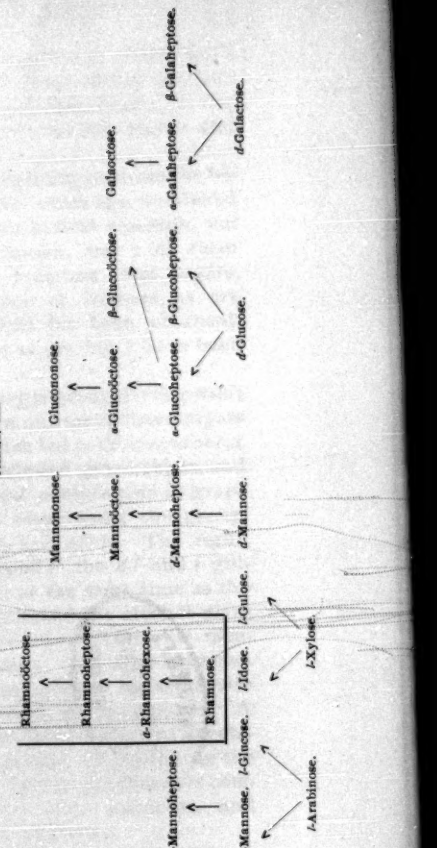
[8] See Table I.

TABLE II.

	Aldose.	Mono-basic Acids.	Di-basic Acids.	Polyvalent Alcohol.
Biose	Glycolaldehyde.	Glycolic acid.	Oxalic acid.	Glycol.
Triose	Glycerose. (*Mixture of aldose and ketose.*)	*d-l-i*—Glyceric acid.	Tartronic acid.	Glycerine.
Tetrose	Erythrose.	Erythritic acid.	4 Tartaric acids.	2 Erythrite.
Pentose	*d-l-i*—Arabinose. Xylose. *l*—Ribose.	*l*—Arabic acid. Xylonic acid. *l*—Ribonic acid.	*l*—Trioxyglutaric acid. Xylo-trioxyglutaric acid (inactive). Ribo-trioxyglutaric acid (inactive).	*l*—Arabite. Xylite (*inactive*). Adonite (*inactive*).
Methyl Pentose	Rhamnose. Chinovose. Fucose.	Rhamnic acid.		Rhamnite.
Hexose — Mannite Group	*d-l-i*—Glucose. *d-l-i*—Gulose. *d-l-i*—Mannose. *d-l-i*—Idose.	*d-l-i*—Gluconic acid. *d-l-i*—Gulonic acid. *d-l-i*—Mannic acid. *d-l-i*—Idonic acid.	*d-l-i*—Saccharic acid. *d-l-i*—Manno-saccharic acid. *d-l-i*—Ido-saccharic acid.	*d-l*—Sarbite. *d-l-i*—Mannite. *d-l*—Idite (1).
Hexose — Dulcite Group	*d-l-i*—Galactose. *d*—Talose.	*d-l-i*—Galactonic acid. *d*—Talonic acid.	Mucic acid (inactive). *d-l*—Talo-mucid acid. Allo-mucic acid.	Dulcite (inactive). *d-i*—Talite.
Methyl-hexose	α—Rhamno-hexose.	α—Rhamno-hexonic acid. (2) β—Rhamno-hexonic acid.		α—Rhamnohexite.
Heptose	*d-l-i*—Manno-heptose. α—Gluco-heptose. β—Gluco-heptose. α—Gala-heptose. β—Gala-heptose.	*d-l-i*—Manno-heptonic acid. α—Gluco-heptonic acid. β—Gluco-heptonic acid. α—Gala-heptonic acid. β—Gala-heptonic acid.	*d*—Manno-heptanpentoldic acid. α—Gluco-heptanpentoldic acid (inactive). β—Gluco-heptanpentoldic acid. α—Gala-heptanpentoldic acid. β—Gala-heptanpentoldic acid.	*d-l-i*—Mannoheptite (Perseit). α—Glucoheptite (inactive). α—Galaheptite.
Methyl-heptose	Rhamno-heptose.	Rhamno-heptonic acid.		
Octose	Manno-octose. α—Gluco-octose. Gala-octose.	Manno-octonic acid. α—Gluco-octonic acid. β—Gluco-octonic acid. Gala-octonic acid.		Manno-ocitte. α—Gluco-octite.
Nonose	Manno-nonose. Gluco-nonose.	Manno-nononic acid. Gluco-nononic acid.		Gluco-nonite.
Aromatic Series	Phenyltetrose.	Phenyltetronic acid.		(1) Ber. **28**, 1975.

	Ketose.	Structure Unknown.	Aldehyde Acids.	
Triose	Dioxyacetone (contained in glycerose).		$(CHOH)_4 < \begin{matrix} COOH \\ COH \end{matrix}$	Glucuronic acid. Oxygluconic acid.
Hexose	*d-l-i*—Fructose. Sorbose.	Formose. β—Acrose.	$(CHOH)_3 < \begin{matrix} COOH \\ COH \end{matrix}$	Aldehydgalactonic acid.

TABLE III.



groups standing at each end of the carbon chain when the acid is turned in the same plane on the diagram as the alcohols, it will be seen that one acid configuration results from two sugar ones, as in the former case of the alcohols.

There are only four alcohol and acid isomers for the eight sugar isomers in this group. In the other higher sugar groups, the conditions are somewhat changed. But by studying the results of oxidation or reduction on sugars, it may be shown that the compounds so obtained point to the probable configuration of a given sugar; and in this way, these formula express the conclusions of actual experiment.

These active asymmetrical compounds are obtained directly from natural products, or are derived from optically active compounds. If compounds are formed from inactive ones, and inactive modifications arise, these inactive forms must be decomposed in order that the active form may appear.

Although these active compounds are the resultants of accompanying life processes, they are not regarded by the chemical thinkers of the day as essentially due to a life force. Fischer believes that these active compounds will all be made synthetically. This is by no means assuming that the knowledge to fabricate these active substances will give into the hands of the chemist the secret touch to set these molecules into a life mechanism.

The example of the glorious period of the highest achievements in Greek art remains as a reminder that neither the skill of a Phidias nor a Praxiteles could give to their creations the breath of life. The analagous height and limit of relative perfection in attainment is seen in other developments of human conception. Each later development may reach a higher round of the ladder than its predecessors, and the standpoint of vision may be a line nearer that goal which seems to recede as the effort of advance reaches forward.

An Arabian alchemist, it is said, first obtained grape sugar, or glucose, in a solid form, by concentrating grape sap. It was obtained pure by the chemist Marggraf, in the middle of the last century. The conversion of starch into grape sugar by boiling with dilute acids was discovered by

Kirchhoff, in 1811. No less interesting is the recent work of Rohmann, wherein he shows that blood serum converts potato starch into dextro-glucose, and that finally, at the end of the reaction, maltose, likewise soluble starch and dextrine, remain.

From all sources the number of simple sugars, from the beginning of the century to less than ten years ago, numbered not over 6. Now, by means of synthetical research, not less than 30 simple sugars are known, and 7 of them are natural products. Among the 7 carbon atom sugars, by calculating the possible number of isomers, 32 are possible, of which only 6 have thus far been obtained. Of the 128 possible nonnose sugars, as yet but 2 have been made.[9]

To carry out the thought of the sugar group development it will be necessary to give rapidly an outline of these sugars before summing up the methods which led to their synthesis.

Under the mannite group are included grape sugar, and sugars possessing the same chemical composition as grape sugar. The mannose sugars also come under this group, with their corresponding alcohols and acids. The right, left and inactive mannose correspond to the *d-l* and *i* glucose. The right mannose is formed at the same time as the right fructose, by the careful oxidation of the alcohol mannite. It was first obtained in this way. It may be mentioned that mannite is found in manna. Mannose may also be obtained from the natural carbohydrates by hydrolytic reaction. It is also found in the fruit of many palms. A very cheap source of supply is from the shavings of vegetable ivory in the manufacture of buttons. In separating the right mannose from its solutions, its phenylhydrazone compound is used. This compound is very insoluble, and affords a characteristic test for this substance.

The left mannose is obtained from the left arabinose. The arabinose compounds contain 5 atoms of carbon.[10] The cyanhydrine reaction in the sugar series, or Kiliani's reaction, is the one employed in its formation. This

[9] The table shows the present sugar status.

[10] By right, left and inactive acids, of course, is meant the effect of these compounds on polarized light.

method has opened the field to some of the most important discoveries in sugar synthesis. In this reaction prussic acid unites directly with sugar,[11] and in this way the number of carbon atoms in the sugar chain may be increased and a higher synthetic compound formed. Upon the addition of prussic acid to sugar compounds, the further processes of saponification and reduction are necessary before obtaining a higher sugar. By this method it is possible to pass from sugars containing a few carbon atoms to sugars representing a higher synthetical series. However, this method can only be used with sugar compounds containing not less than 3 carbon atoms. Such compounds have the power of forming lactones, and sugars of a higher carbon percentage are obtained by reducing these lactones.[12] It is by the use of this method that Fischer has obtained some of his most brilliant achievements.

The right, left and inactive glucose and idose, which are stereomers of glucose, have been obtained synthetically from their corresponding acids. Idose is named from the symmetrical form of its molecule, and is among the latest discovered compounds of this group. The acids of these last two sugars are isomeric with the sugar acids obtained by oxidizing glucose and mannose.

Two other sugars, which may be mentioned as belonging to the hexoses, are galactose and talose. The right, left, and inactive galactose have been obtained. The *d*-galactose as well as the *d*-glucose may be derived from milk sugar by hydrolysis. The latter may also be obtained by the same means from other carbohydrates. Galactose yields, on reduction, an alcohol called dulcite. These

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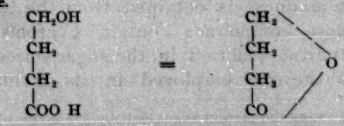
[11] $C_4HOH(CHOH)_4CHO + HCN = CH_2OH(CHOH)_4CHOH.CN + H_2O$.

[12] The lactones are gamma hydroxy compounds, which, by the loss of water, give an anhydride.



Counting from the one above the bottom group, the carbons are known as the alpha, beta, gamma, delta carbons, etc.

sugars belong to the second division of the hexose group, known as the dulcite group, and by oxidation yield mucic acid; whereas the sugars of the mannite division yield, on oxidation, saccharic acid. All these sugars may be separated from their solutions, in a solid form, by means of their hydrazones and osazones.[13] However, with the exception of mannose, the hydrazones of other sugars are mostly soluble in water. Hence, the reaction with phenylhydrazine is carried on to a further state, which results in the formation of the insoluble osazones. These compounds differ decidedly in color and system of crystallization. They have sharp melting points, which lead to their easy identification.

Another class of substances, which are called mercaptales, are compounds of sugar with sulphur, of the composition, $CH_2OH(CHOH)_4CH(S_2C_2H)_2$, furnishes a means of separating and distinguishing the aldehyde sugar compounds.

The synthetical sugars containing 7, 8 and 9 carbon atoms, derived from the groups containing less carbon atoms, may be made by Kiliani's method.

It is an interesting fact that the sugars containing 3, 6 and 9 atoms of carbon are fermentable; while those containing 4, 5 and 7 atoms of carbon cannot be fermented.

Fischer has suggested wherein the interest of these massive sugar molecules lies. It is in physiological research. He has proposed, as worthy of attention, that these higher synthetical sugars be experimented with as to their full physiological value. Possibly the tissues of animals nourished with these higher sugars may yield other chemical products; the liver may give a new glycogen, and a new acid may be found in the milk secretions from the mammary glands. Here may possibly be opened a new research ground for the biologist.

The pentosanes are compounds belonging to the sugars containing 5 carbon atoms. These pentosanes occur in various parts of plants of different age and development. The amount increases during the development of the plants. The wood of dicotyledonous plants is richer in pentosanes

[13] The reaction and products of some of these sugars were demonstrated.

than those of the *Coniferæ*. It is thought by de Chalmot that these substances are reserve materials. But they seem of importance in the formation of wood, for they are developed at *this* stage.

Arabinose is one of the important members of the pentose series. It was discovered by Scheibler on boiling the gum of the cherry tree with sulphuric acid. This compound was considered by him an isomer of grape sugar; but it was shown by Kiliani to possess the formula $C_5H_{10}O_5$. Although the natural arabinose turns the plane of polarized light to the right, on account of its relation to *l*-glucose, it should be considered as a left compound. Artificially, the right turning arabinose may be made from glucose by a *building-down* process, as it were, discovered by Wohl. This process consists in passing from a sugar richer in carbon atoms to one containing fewer carbon atoms.

On boiling bran, wood, jute, straw and like substances, with acids, pentosan compounds are obtained. In some cases they may be isolated, or their presence may be proved by the furfurol reaction. This is a well-known test for their identification. If compounds belonging to the hexose groups be heated with acid, they yield lævulinic acid ($CH_3COCH_2CH_2CO_2H$). On the contrary, pentose compounds, by distillation with strong acids, yield furfurol compounds, which easily pass over with steam.

The portions of the coffee berry insoluble in water, when distilled with dilute hydrochloric acid, yield furfurol aldehyde, which demonstrates the presence in the coffee of a compound belonging to the pentosanes.

By warming with phloroglucin and hydrochloric acid, the pentosanes, as also all compounds which, by decomposition, yield sugar compounds containing 5 carbon atoms, give a cherry-red color reaction.

Ribose, a colorless syrup, and xylose, wood sugar, are isomeric with arabinose.

Rhamnose, formerly erroneously called "isodulcite," is a methylpentose. It is obtained from datiscin by hydrolytic reaction, and by the same method from different glucosides.

Fucose, obtained from the sea-tangle or grass mack, is

isomeric with rhamnose, also chinovose, which is derived from chinovite. The alcohols, xylite and adonite, belonging to the sugars xylose and ribose, correspond to arabite, the alcohol of the sugar arabinose, and are inactive.

The remaining series of compounds, which chemically belong to the same class as the sugars, are designated as biose, triose and tetrose sugars. These compounds contain, respectively, as their names indicate, 2, 3 and 4 carbon atoms. The latest addition to this list is the number containing the fewest number of carbon atoms. This is a compound with two atoms of carbon, chemically known as glycol aldehyde, and may be obtained from brom-acetaldehyde, by means of barium hydrate in the cold. This compound possesses all the properties to be expected from a simple sugar. Of these, the property of being converted by phenylhydrazine into the gloxalosazone may be mentioned. It has not been possible to obtain the glycolaldehyde *from admixture* with the brom-aldehyde from which it is derived; consequently, the behavior of this simple sugar with ferments has not been proven. Since brom-compounds act as a poison towards yeast, the mixture will probably be found not to ferment.

Triose or glycerose is considered to be a mixture of glycerin aldehyde (CHOH . CHOH . CHO) and dioxyacetone (CHOH . CO . CHOH). This compound is a syrup, and reduces Fehling's solution, and actively ferments with yeast.

The chemical sugar next higher in the scale is the tetrose sugar, which is formed by the oxidation of erythrit, and is named therefrom erythrose. This is likewise a mixture of aldehyde and ketone compounds. The regeneration of this sugar from its osazone has not yet been accomplished. The synthetical tetrose probably arises by a kind of aldol condensation. It has been isolated in form of its osazone only, which is identical with the erythrosazone.

It may be mentioned in reference to aldol condensation, that it is of two kinds. The condensation may be accompanied either by the loss of a molecule of water or by no loss of water. The former is known as aldehyde condensation, when, for example, two molecules of ethylaldehyde

are heated with zinc chloride, and a molecule of water is lost. In the latter case, the aldehyde must stand for a longer time with dilute hydrochloric acid; thence arises a condensation product known as aldol condensation.

The distinctions between the sugars characterized as the aldose and ketose sugars disappear when these sugars are converted into the osazones; for each sugar gives identically the same osazone, and this compound affords a means of passing from a sugar of one class to a sugar of the other class.

The other division of natural sugars, or the ketone sugars, of which fructose is the type, includes, up to the present time, three representatives only. Of these three sugars, only the dextra-fructose combines with prussic acid; consequently, the synthesis in this division by Kiliani's method is limited. It has not gone beyond the fructo-heptose, or a ketone sugar containing 7 atoms of carbon.

Fructose is the fruit sugar to which the sweetness of fruits is chiefly due. This sugar crystallizes from alcohol in crystals belonging to the rhombic system, whilst the crystals of glucose are obtained as fine needles. Fructose occurs in three modifications. The inactive modification is of historical interest, since it was the first synthetic sugar made out of materials obtained by synthetical means.

Of the methods which serve for the direct synthesis of sugar may be mentioned: (1) the polymerizing of formyl-aldehyde by bases; (2) a valuable synthetical means is, likewise, the reaction which corresponds to aldol condensation; and (3) Kiliani's method has been of untold value in this field; (4) the artificially made sugars may be separated from solution in form of their osazone compounds, and, in most cases, the sugars can be regenerated from these compounds.

In all cases a mixture of these osazones arise. The inactive phenyl-glucosazone is the direct source of the inactive fructose; for, by reducing the osone derived from the osazone, a ketose arises which agrees in all respects with the inactive form of fructose. It possesses all the properties of the natural fruit sugar.

By the reduction of this inactive fructose, obtained synthe-

tically, arises the inactive mannite. The synthesis of the active glucose and fructose (the natural sugars) may be made from the inactive mannite in the following way: By treating the inactive mannite with the suitable oxidizing agent, it will be oxidized to the inactive mannose and the inactive mannonic acid; the inactive mannonic acid can be split into its active constituents, the right and the left acids. The right mannonic acid yields, by reduction, the right mannose on the one hand, while on the other, by heating with chinolin or pyridin, a molecular change takes place, and the *d*-gluconic acid is obtained, which yields the active glucose. Finally, the active glucose and mannose, through their phenyl-glucosazones, may be converted into the active fructose. Thus the problem of the synthesis of the most important natural sugars has been accomplished.

Sugar, as a class, is thus derived not only from sources pertaining to the land and sea, but also, from the brief sketch just drawn, from no less a source than man's intelligence.

According to the earliest records, the sugar cane, the main source of the supply of saccharose or cane sugar, was cultivated in India for food supply. The beet sugar industry dates from our own time.

Cane sugar is found in many plant species, and occurs in grain during germination at the expense of starch, as it was observed in the barley. Cane sugar has not yet been made synthetically. It stands as one of the atomic peaks still to be scaled.

The discovery, by Biot, of the power of cane-sugar solutions to turn the plane of polarized light led Dubrunfaut, in 1847, on decomposing cane sugar, to discover fructose, the second sugar constituent of cane sugar. In the same way, we may read any day the announcement of the discovery of a chemical spy-glass, which will reveal the pathway to the synthesis of this member of the chemical chain.

Maltose, a sugar of the same composition as cane sugar, was discovered by Dubrunfaut. Maltose, a polysaccharide, has been made synthetically.

Milk sugar, which also belongs to this same division, was separated from milk as early as the year 1619, by

Bartoletti, of Bologna. Demole claims to have made it synthetically.

Starches, gums, cellulose and mucous compounds are of great physiological interest in their bearing to plant life, and the recent thorough investigations of the sugar groups will not be unavailing to bring forward a clearer knowledge of these bodies. There are many sources of starch, and some peculiarities between the different kinds. Lichenin, from Iceland moss, and inulin, from many composital plants, act the *rôle* of starch in the plants wherein they occur.

A brief reference may be given here to compounds like dextrine and lævulin, which stand intermediary between the starches and sugars. Dextrine is formed from starch by treating with dilute acids, or by diastase. According to the conditions, several dextrine kinds may be separated. A crystalline form, produced by the action of dilute mineral acids on starch for months, has been isolated. Dextrine gives with iodine a red coloration.

Glucosides are compounds of grape sugar or glucose with another substance, and naturally find place in a study of carbohydrates. Grape sugar, on account of its containing an aldehyde group, is capable of uniting with different kinds of chemical bodies to form these compounds. The compound which results on decomposing a glucoside is frequently of a complex nature. Glucosides are very widely spread in nature. In many cases the chemical constitution of glucosides is well known, and some of these compounds have been made synthetically.

Recently, Fischer has described a method of obtaining glucosides synthetically. By the action of hydrochloric acid on sugars, alcohols, oxyacids and phenols, he obtained condensation products of the nature of glucosides. These compounds, like other glucosides, do not react with Fehling's solution or with phenyl-hydrazine. But they are decomposed by acids.[14]

[14] Also ketones, by warming and treating with hydrochloric acid, are changed into glucosides. Ketones combine with sugar; rhamnose with one molecule; arabinose, fructose and glucose unite with two molecules of acetone; sarbose, with a ketosane, yields a beautiful crystalline compound. By

These simple compounds are analogous to the more complex ones, and are of interest for their bearing on the natural glucosides. There is no essential difference between the simple synthetical glucosides and the more complicated carbohydrates like cane sugar. Indeed, the latter should be considered as the glucosides of sugar.

The list of natural glucosides is a long one. A summary of their particular occurrence and properties is unnecessary here. But a glucoside, for example, like either saponin or phloridzine, illustrates the fact that compounds of a like composition are found in closely related botanical families. Plants in which saponin occurs are nearly related in regard to their stage of evolution, and so with phloridzine-containing plants. Phloridzine, when isolated from the bark of the apple, cherry or plum tree, or from other plants belonging to the order *Pomaceæ*, is a crystalline substance of a white color when quite pure. Like all glucosides, it is decomposed by dilute acid into glucose and a second product. In this case the second product is phloretin.

From experiments on animals, phloridzine, when taken into the body, produces a condition which results in diabetes. The amount of sugar excreted from the system after ingestion is far in excess of what could be produced from the glycogen of the liver, nor would the amount of glucose in the glucoside explain the large quantity of sugar excreted. But, in fact, according to Cremer, the phloridzine passes through the system unchanged, and the sugar which arises is from the proteids of the body.

The very latest trend of investigation is to show that the

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employing a very weak solution to work with, in contradistinction to the former work with strong hydrochloric acid, α- and β-stereomers were obtained, also a third product, an acetal compound, analogous to the glucose mercaptans. In the beginning these are in excess, then they go over into glucosides.

The ketose sugars react with alcohol, in presence of HCl, more quickly than aldosans.

Fischer has also discovered, as a between-product, glucose-acetone, which is separated in fine, colorless needles. This compound is distinguishable from the glucose di-acetone.

A new glucoside, similar to amygdalin, but of a simpler formula, named amygdonitril glucoside, has been recently described by Fischer.

configuration of a compound has its place in the explanation of the functions of an organism. Also, the reasons for the fermentation of certain compounds are to be found in stereo-chemical considerations.

It is stated in a recent publication that the most ordinary functions of a living being depend more upon the molecular geometry than upon the composition of the food material. It is well known that the fermentation processes are brought about by minute organisms, and it is supposed that the geometrical configuration of the ferment coincides with that of the compound which it attacks. The most important chemical agents of the living cell are the optically active ones of the albuminoids, and these possess, consequently, an asymmetrically constructed molecule. Since the simple albuminoids result from the sugars, the fact is given in proof of the same geometrical structure for these two classes of bodies. On this reasoning it has been claimed that, when sugar comes into contact with the albumen of the yeast cells, fermentation only takes place if the geometrical form of the sugar molecule does not differ too widely from that of the yeast substance.

In some recent experiments, Fischer found that the ferments invertin and emulsin attack only the glucosides of grape sugar, whilst they leave those of other sugars—likewise starch, salicin, phloridzin and other synthetical phenol-glucosides—unacted on.

However, the α-methyl glucoside is decomposed by invertin and not by emulsin; but with the methyl glucoside the reverse occurs. These facts are given to show that a different molecule structure alters the condition.

The influence of the bacilli on chemical changes in the body is recognized. That these changes do occur is evident. Many experiments on plant tissues show this. The transformation of starch into sugar by the *Bacillus anthracis* has been shown lately by cultivating the bacillus on a potato. After a short time, the surface of the potato gave, not the blue color of starch with iodine, but the red color of dextrin. Portions of the potato were then placed in sterilized water, and, after some days, on testing the liquid, it reduced

Fehling's solution. The explanation of these changes is supposed to rest on the configuration of the molecule.

From the survey of the chart, on which are summarized the synthesis and work on the sugars, the attention of the least interested observer will be called to this fact—that a vast amount of work has been accomplished in this field, and the harmony in these groups between facts and theories is significant. That chemical compounds are *solids* and occupy space is not to be gainsaid, but there must be an adjustment between scientific facts and hypotheses. To pervert or carelessly to observe facts in order to make them, at all hazards, fit into theoretical moulds, is the highest act of treason of which the scientist can be guilty. Chemistry, studied from a geometrical basis, is of comparatively recent date. It is purely arbitrary to settle upon any particular figure to express the grouping of the atoms in space. However, the tetrahedron is the simplest expression that explains the fact.

The entire subject of the chemistry of sugars would be the chaos it was before, without the aid of geometrical speculations. These at once bring order and system to a confusion of facts.

Hegel names time and space the accidents of true existence. In the consideration of the space relations of these compounds a step is taken to the reality which lies beyond time and space and the imperfection of knowledge. These configurations represent crudely the ideal basis of what is called matter.

The next query that will occur to those who are not daily working in scientific matters is this: Is the subject of sugars, just reviewed, settled for all times? In science there is no fixed ground. The true object of scientific research is to seek truth regardless of the consequences, and on our plane, truth is evolving. To embrace, when found, that truth which seems the more evolved, even though the pet hypotheses and results of a lifetime's personal effort are laid aside, is the true aim of endeavor. This is the true scientific spirit. The magnetic needle oscillates until it finds its resting place pointing northward, and the chemist, too,

should oscillate within the arc of his science until he finds the currents flowing towards light and higher truth.

It has been said that "every man who would do anything well must come to it from a higher plane. A philosopher must be more than a philosopher." Plato was clothed with the powers of the poet, though he chose to use his poetic powers to an ulterior purpose. In the love for facts, the other side of the subject, the "mirror image," so to speak, must not be forgotten. It is from the employment of the imagination and the cultivation of the higher reasoning faculties that the true insight will come. This insight will reveal the meaning of all these phenomena, and the oneness underlying all things will become apparent. To cleanse the eye from seeing only the grosser phenomena, and to gain the perfect faultless eye of wisdom, compensated Kunala, the king's son, for the loss of his eye, which, by a cruel order, was torn from its socket.

The more apparent phenomena of a science have their true place when studied in harmony with the bold outlines of the universe. Call these outlines philosophical principles, cosmic laws, or what you will, but the facts of science, culled from many fields, only confirm the words of long ago: "Our whole existence depends on our thought; thought is its noblest factor; in thought its state consists."

Chemical facts, or the facts of any science when regarded, not as the end of endeavor, but as the means to an end, take their true place in the intellectual universe.

The facts of a science being more or less relative, in the search of truth these relative facts are useful, inasmuch as they indicate the principle which underlie the manifestations.

The ceaseless change and interchange; the impermanence of all things in Nature, whether pertaining to the so-called inorganic or organic life phenomena, is expressed by the mutations and transformations of chemical reaction.

The recurrent properties and the chemical laws, exhibited in all syntheses, as well as in breaking down processes of compounds, are in unison with the rhythmic system of evolution from which nothing in this universe can escape.